Technical Report HL-92-7
September 1995

US Army Corps of Engineers
Waterways Experiment Station

Houston-Galveston Navigation Channels, Texas Project

Report 4
Three-Dimensional Numerical Modeling of Hydrodynamics and Salinity

by R. C. Berger, Robert T. McAdory, Joseph H. Schmidt, William D. Martin, WES
Larry H. Hauck, Jones and Neuse Engineering

Prepared for U.S. Army Engineer District, Galveston

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Report 4 of a series

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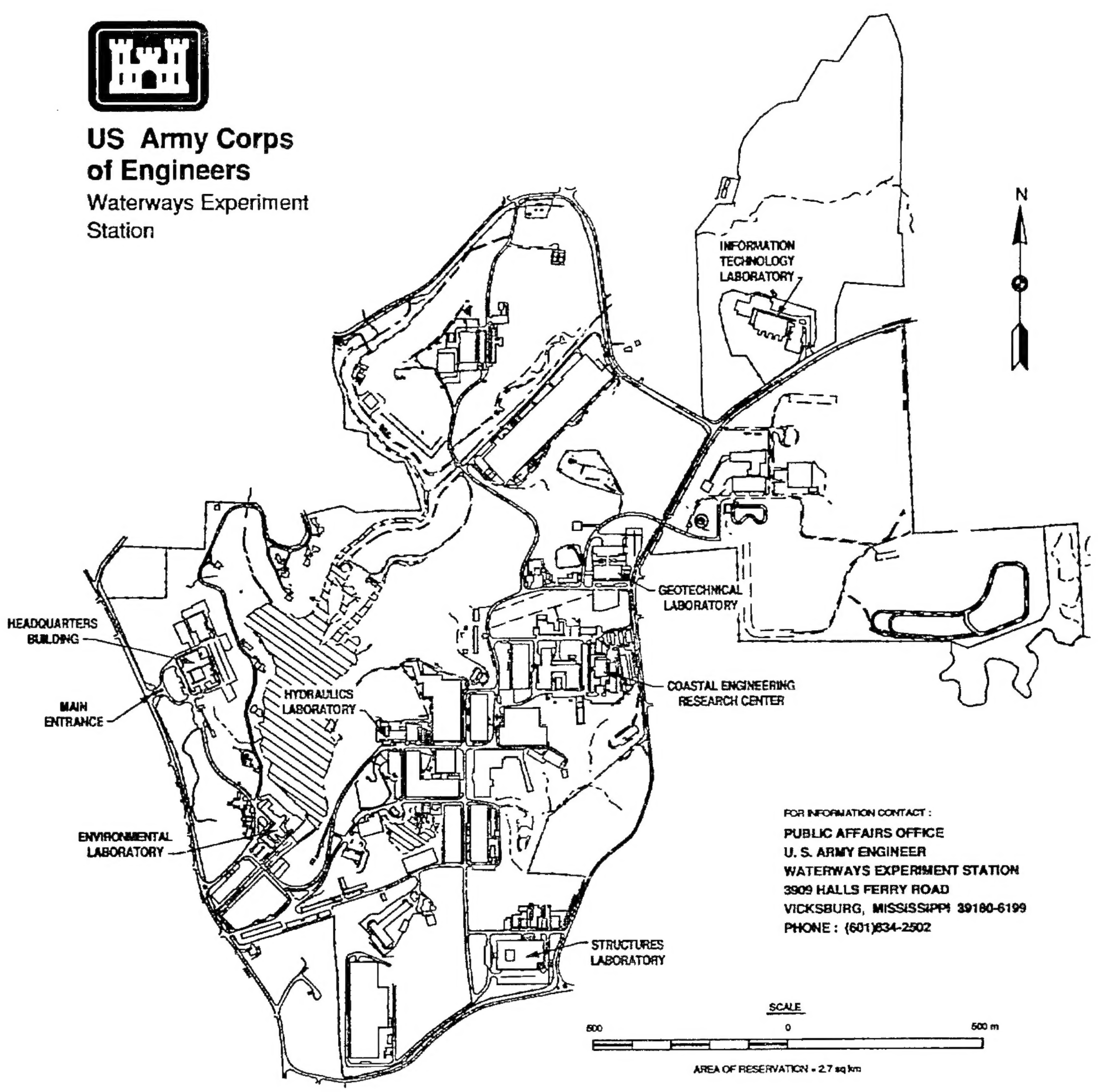
Waterways Experiment Station



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Preface

The three-dimensional numerical modeling testing of hydrodynamic and salinity conditions for the Houston-Galveston Navigation Channels, Texas Project, as documented in this report, was performed for the U.S. Army Engineer District, Galveston (SWG), by personnel of the Hydraulics Laboratory (HL) of the U.S. Army Engineer Waterways Experiment Station (WES). The testing program reported herein occurred from February 1992 through January 1995. The study began in October 1990. The Houston-Galveston Navigation Channels, Texas Project, study was authorized by House Document 350, 85th Congress, 2nd Session, and by House Document 427, 86th Congress, 2nd Session. The subject study was authorized by SWG in conjunction with the study cost-sharing partner, the Ports of Houston and Galveston, Texas, on 3 April 1990.

This is Report 4 of a series. Report 1 describes the data collection, Report 2 is the two-dimensional modeling of hydrodynamics for the navigation study, and Report 3 describes the verification of the three-dimensional model for hydrodynamics and salinity.

The study was conducted under the general supervision of Messrs. F. A. Herrmann, Jr., Director, HL; R. A. Sager, Assistant Director, HL; W. H. McAnally, Jr., Chief, Waterways and Estuaries Division (WED), HL; and W. D. Martin, Acting Chief, Hydro-Science Division (HSD), HL.

This work was performed and the report prepared by Dr. R. C. Berger and Dr. R. T. McAdory, WED; Messrs. J. H. Schmidt and Martin, HSD; and Mr. L. H. Hauck, previously associated with WED and Jones and Neuse Engineering. Much of the daily activities such as checking run status, plotting, and data storage was performed by Messrs. Jay Hardy and Lenwaski Campbell, WED, and Ms. Cassandra Gaines, HSD.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acre-feet	1,233.489	cubic meters
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
miles (U.S. nautical)	1.852	kilometers
miles (U.S. statute)	1.609347	kilometers

1 Introduction

Background

In the 19th century Galveston Bay existed as an immense shallow estuary accessible to light-draft vessels. Conditions then, as today, created a fertile source for shell and fin fish. Areas of the bay, such as Red Fish Reef, were, according to verbal records, so shallow that during low tides cattle could be driven across the bay. Subsequently, as the Texas Gulf Coast developed, channels were constructed to provide access to Galveston, Texas City, and Houston, TX, for increasingly deeper draft vessels. A brief chronology of the deepening is shown in Table 1.

Table 1
Chronology of Houston Channel Deepening, Galveston Bay (from Alperin 1977)

Date	Channel Minimum Depth, ft	Channel Width, ft
1851	4	-
1870	4	70
1874	9	120
1889	12	100
1893	14	100
1903	18.5	150
1914	25	150
1926	30	250
1932	32	250
1936	34	400
1948	36	400
1964	40	400

The currently proposed Houston-Galveston Navigation Project is the latest attempt to maintain the competitiveness of this area in the world trade market.

Houston is currently the number two port in the United States based on tonnage handled, rated behind only New Orleans ("The U.S. Waterway System Fact Card" 1991).

The project was originally proposed for construction in two construction phases. In Phase I, the Houston Ship Channel (HSC) will be enlarged to a depth of 45 ft[1] and widened to a width of 530 ft, and the Galveston Channel to a depth of 45 ft and a width of 450 ft. In Phase II, both channels were to be deepened to 50 ft and HSC widened to 600 ft. Current plans do not include the Phase II enlargement. Both channel depth conditions were analyzed before this decision was finalized and are thus included in this report. In the remainder of the report, the 45-ft-deep channel is designated as Phase I and the 50-ft-deep channel as Phase II. The study area is shown in Figure 1.

Objectives

There are several related objectives of this study:

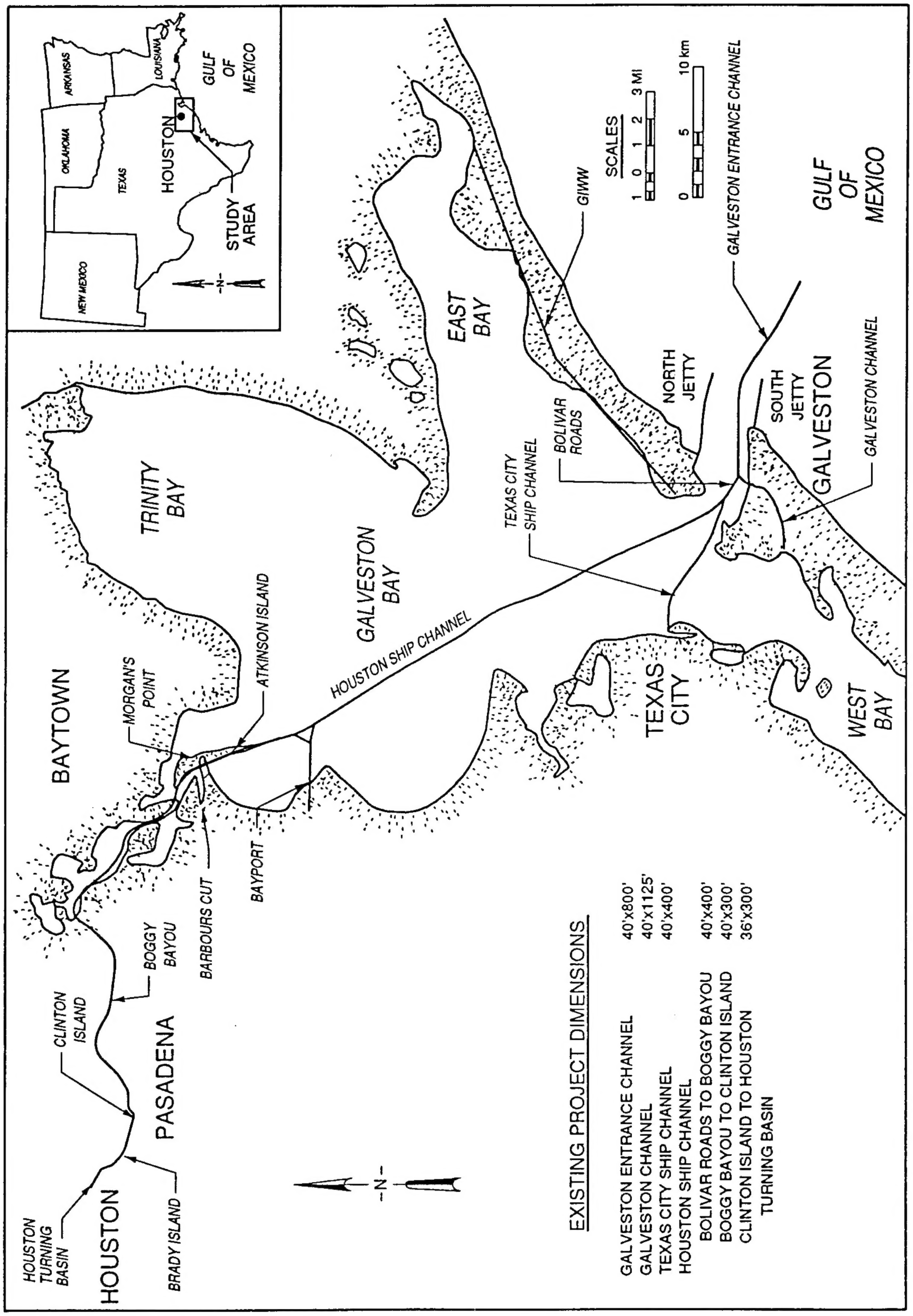
a. Develop an accurate, verified three-dimensional hydrodynamic and salinity model of Galveston Bay for the conditions existing in late 1990.

b. Using this model, evaluate the effects of changes due to proposed channel deepening on circulation and salinity within the bay.

c. Evaluate the effects of the channel deepening under several predicted future changes in freshwater inflow.

d. Provide the output from these model runs as input to a comprehensive model for evaluating oyster population response to the changed conditions modeled.

[1] A table of factors for converting non-SI units of measurement to SI units is found on page vi.



EXISTING PROJECT DIMENSIONS

GALVESTON ENTRANCE CHANNEL	40'x800'
GALVESTON CHANNEL	40'x1125'
TEXAS CITY SHIP CHANNEL	40'x400'
HOUSTON SHIP CHANNEL	
BOLIVAR ROADS TO BOGGY BAYOU	40'x400'
BOGGY BAYOU TO CLINTON ISLAND	40'x300'
CLINTON ISLAND TO HOUSTON TURNING BASIN	36'x300'

Figure 1. Location map of Houston-Galveston Navigation Channel Project

2 Development of the Model

Development of the Scope of Work

From the inception of the studies at the U.S. Army Engineer Waterways Experiment Station (WES), interagency coordination was an integral part in developing the scope of work and reporting progress. The Interagency Coordination Team (ICT) provided the forum for discussions of the scope of work for the WES studies in addition to the many other topics and studies that are part of the Houston-Galveston Navigation Project. Member organizations of the ICT include U.S. Army Engineer District, Galveston; Houston Port Authority; U.S. Fish and Wildlife Service; U.S. Environmental Protection Agency; National Marine Fisheries Service; Texas Governor's Office; Texas Parks and Wildlife Department; Galveston Bay National Estuary Program; and Galveston Wharves. Over the period January 1990 through September 1990, WES and ICT went through an interactive process, which culminated in a final scope of work from WES dated September 27, 1990. In the process of developing the scope of work, WES personnel attended the ICT meetings on approximately a monthly basis for presentation of the evolving scope, and also to present progress on studies that had prior endorsement from the ICT, for example, the velocity development for the ship simulator studies and initial phases of the field investigations.

As part of the interagency coordination, the WES staff provided a presentation on April 12, 1990, to the Ocean and Estuarine Physics Branch, National Ocean Service (NOS), a sister organization to the National Marine Fisheries Service, both in the National Oceanic and Atmospheric Administration (NOAA). In this presentation, a comprehensive description of the state-of-the-art three-dimensional (3-D) model, RMA10-WES, was provided to the NOS staff. A series of phone conversations and letters ensued with NOS agreeing that the RMA10-WES model should be capable of addressing the objectives of the Galveston Bay Study.

Final agreement to the field investigation plan was reached during a meeting on September 13, 1990, of U.S. Army Corps of Engineers, NOAA (NOS and National Marine Fisheries), and Council on Environmental Quality, which resulted in a statement of agreement. The agreement to the field investigation involved the following two major items: (a) extension of the long-term

instrument deployment from 120 days to 180 days (July 19, 1990, to mid-January, 1991), and (b) redeployment of several of the moored current meters and salinometers to new locations in October or November. These field investigation modifications allowed extension of instrument deployment into the winter to record frontal passages, which are important meteorological events influencing bay circulation. Also, the instrument redeployment allowed dual emphasis of data gathering—the HSC for the first half of the study and the shallows, especially Trinity Bay, for the last half. The results of the field data collection effort are presented in Fagerburg et al. (1994).

Concurrent with the development of the field investigation scope of work was the development of the 3-D (RMA10-WES) modeling scope of work. The number and length of the RMA10-WES applications were largely determined by the need to simulate the same hydrologic conditions as in the Environmental Impact Statement (EIS) and to provide sufficient hydraulic data to assess project-induced impacts on oysters.

By the summer of 1990, ICT had agreed to the scope of work for a numerical oyster model to evaluate project-induced impacts to oysters. Oysters were selected as the single species whose fate is most indicative of the general bay condition and its impact on other important species. The oyster model studies were directed by Dr. Eric Powell of Texas A&M University. Because the oyster model used currents and salinities from RMA10-WES, the WES 3-D model studies were strongly linked to the oyster model studies. The duration of several key RMA10-WES simulations was dictated largely by the oyster model needs for complete information during the oyster's life cycle. Consequently, for these key hydrologic sequences, simulations of 12-month duration were conducted. Other simulations were run for the period January-September, which encompasses the oyster's annual active stage.

The Model

The task of modeling Galveston Bay in three dimensions while varying the boundary conditions and geometries required use of a sophisticated numerical model. Several models were considered before the RMA10-WES code was chosen. This finite element code allowed easy modification of the geometry and bathymetry. The challenge lay in the length of the simulations. The model had previously been used to model real-time durations of several days; yet the 3-D study required several runs of 1 year and others of 9 months.

The unstructured mesh capability of RMA10-WES allowed flexible resolution that matched small- and large-scale features. Several disposal sites for dredged material are included for both phases. These sites vary from as little as 100 acres to as much as 1,500 acres. They are shown on the computational grids for Phases I and II, to be discussed later in this section. The National Economic Development (NED) plan has the same channel configuration as Phase I but with submerged disposal material placement instead of the islands in Phase I.

The RMA10-WES code is a Galerkin-based finite element solution to simulate 3-D unsteady open-channel flow. The model was originally developed by Dr. Ian King of Resource Management Associates (King 1988) and extensively modified by the WES staff. The code represents 3-D hydrodynamics using conservation of fluid mass, horizontal momentum, and salinity/temperature transport equations. As is typical of shallow-water models, the vertical accelerations are assumed to be negligible (the hydrostatic assumption) and so the vertical velocity is calculated through mass conservation. In the interest of computational efficiency the code also simulates one-dimensional (1-D) and two-dimensional (2-D) flow as well as transitions between 1-, 2- and 3-D. The code is implicit in time and resolves the non-linearities via Newton-Raphson iteration.

In a 3-D model, or a laterally integrated 2-D model, the vertical extent of the domain is not known until the depth is calculated, and, of course, one cannot make the calculations until the computational grid is developed. This apparent impasse is avoided by transforming the domain at each time-step to a static grid. The particular transformation used maps the water surface to a constant elevation, the bed is unchanged, and all elevations in between are stretched proportionally. Five such grids were used for this study. These represented the 1990, or existing, conditions (Figure 2); the 45-ft-deep channel (Phase I) with 17 intermediate mitigation islands added (Figure 3); the 50-ft-deep channel (Phase II) with intermediate mitigation islands added (Figure 4); the NED plan (Figure 5); and the final mitigation plan with 45-ft-deep channels (Figure 6). The characteristics of the grids are summarized in the following tabulation. The mitigation plan run was made to supply the oyster model with data representative of the selected plan of improvement. The oyster model would use these data to determine the size and location of oyster reefs needed to mitigate the adverse impacts of the selected plan.

Condition Modeled	Surface Nodes	Surface Elements	Total Nodes	Total Elements
Existing	6,192	1,996	12,270	5,112
45-ft channel	6,902	2,278	14,477	6,250
50-ft channel	6,902	2,278	14,477	6,250
NED	7,027	2,333	14,990	6,421
Mitigation	7,414	2,451	16,470	7,045

The model is configured as largely 3-D with the exception of the West Bay west of the causeway. The 3-D portion consists of one element (three nodes) in the shallow areas of the bay and up to four elements (nine nodes) in the channel. Figure 7 depicts the 2-D and 3-D portions of the grid. These portions are the same for each case except where mitigation islands are present as solid land mass.

The salinity/density relationship in the model is based on Pritchard (1982).

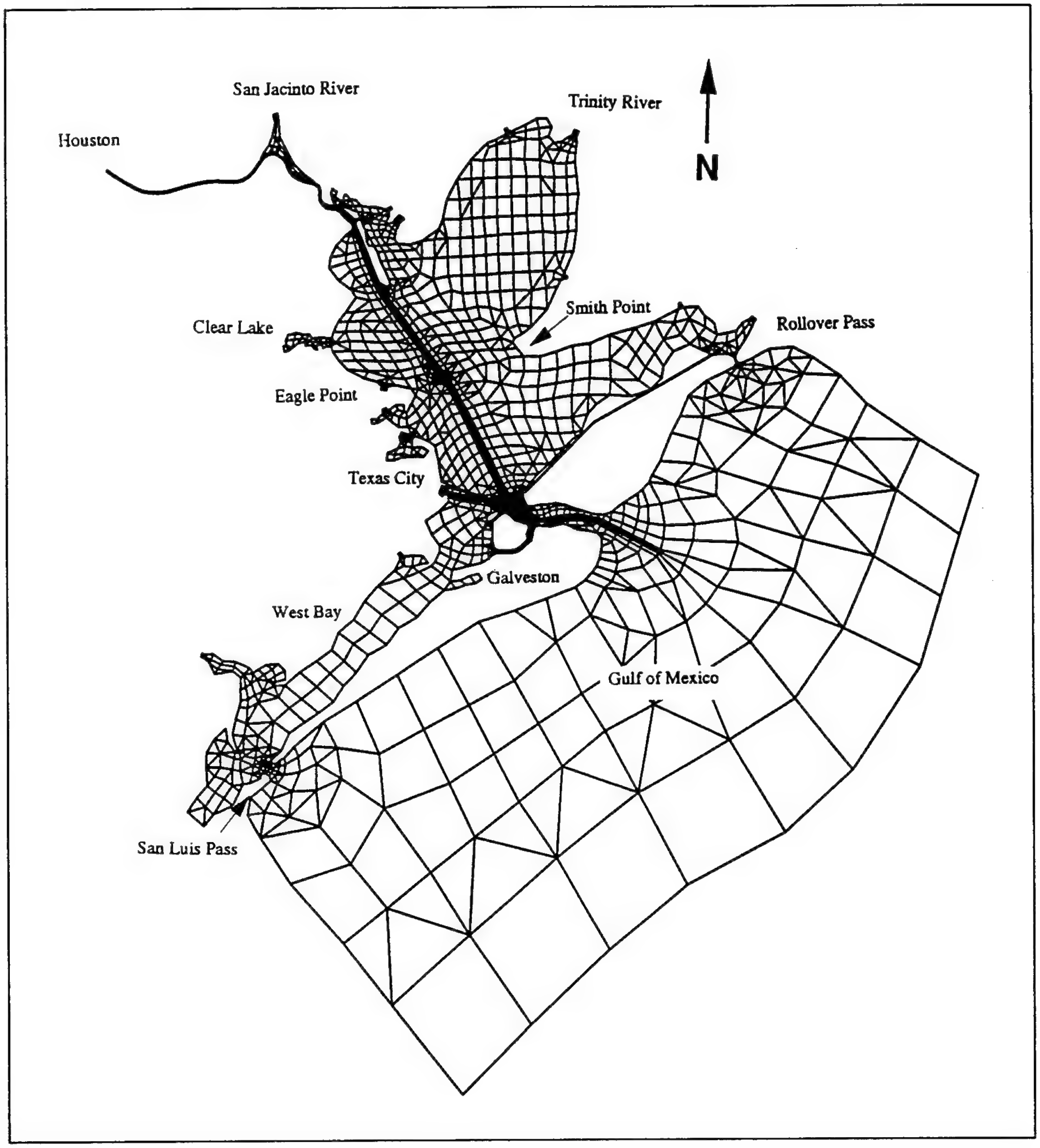


Figure 2. Existing conditions

The vertical turbulence is a combination of the Mellor-Yamada Level II (Mellor and Yamada 1982; Adams and Weatherly 1981) and Henderson-Sellers (1984). The wind stress is a quadratic relationship using the specific coefficients developed by Wu (1980). The effect of wind waves on vertical mixing is simulated in the manner of the numerical model CE-QUAL-W2 (U.S. Army Engineer Waterways Experiment Station, 1986). Details of the model are presented in Appendix A.

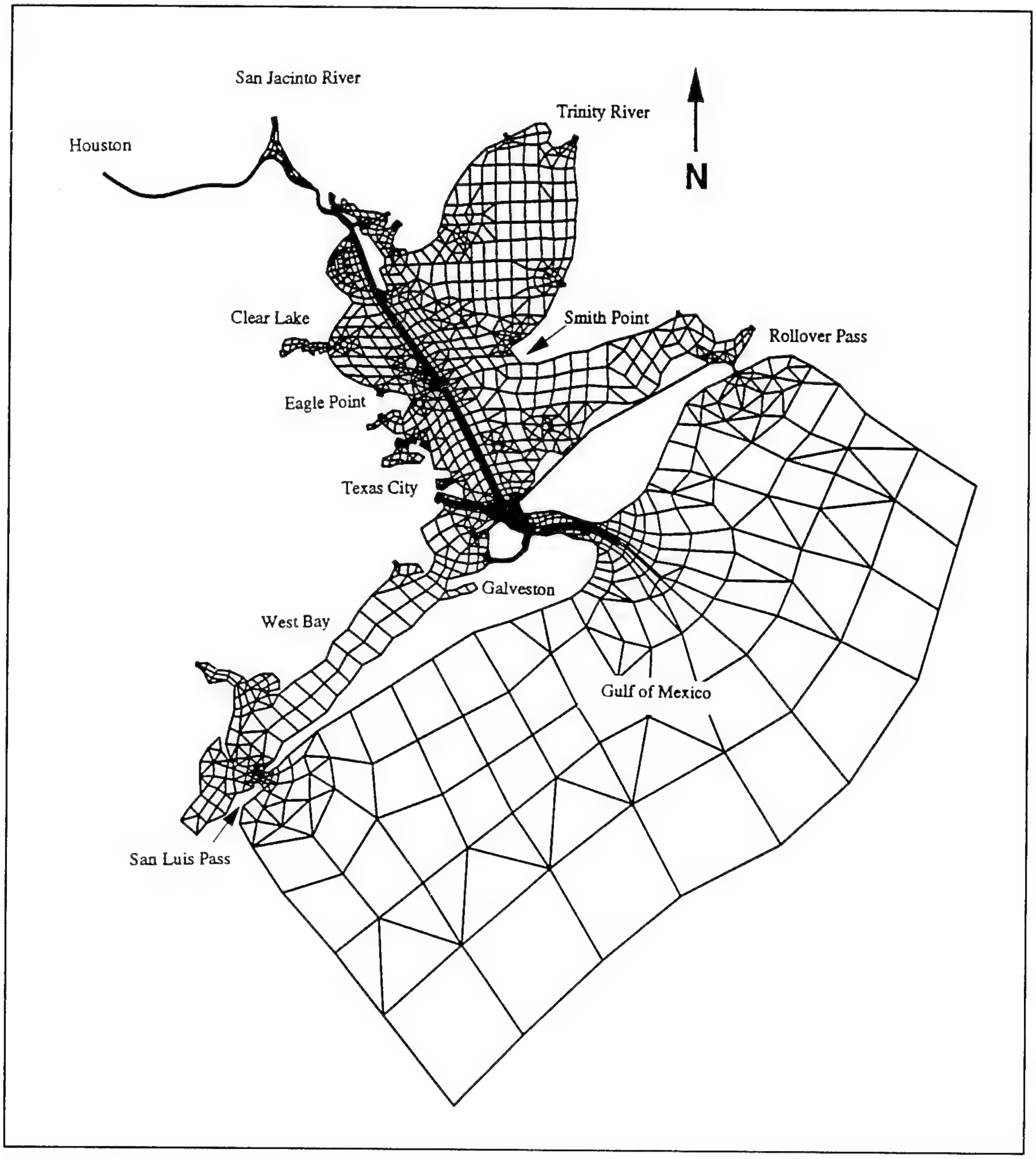


Figure 3. Phase I conditions

Data Requirements

Any model requires extensive field data to ensure that the model is accurately reproducing conditions observed in the field. To this end, tides, salinities, and current magnitudes and directions at several depths were collected at 28 different locations during the period July 1990 through January

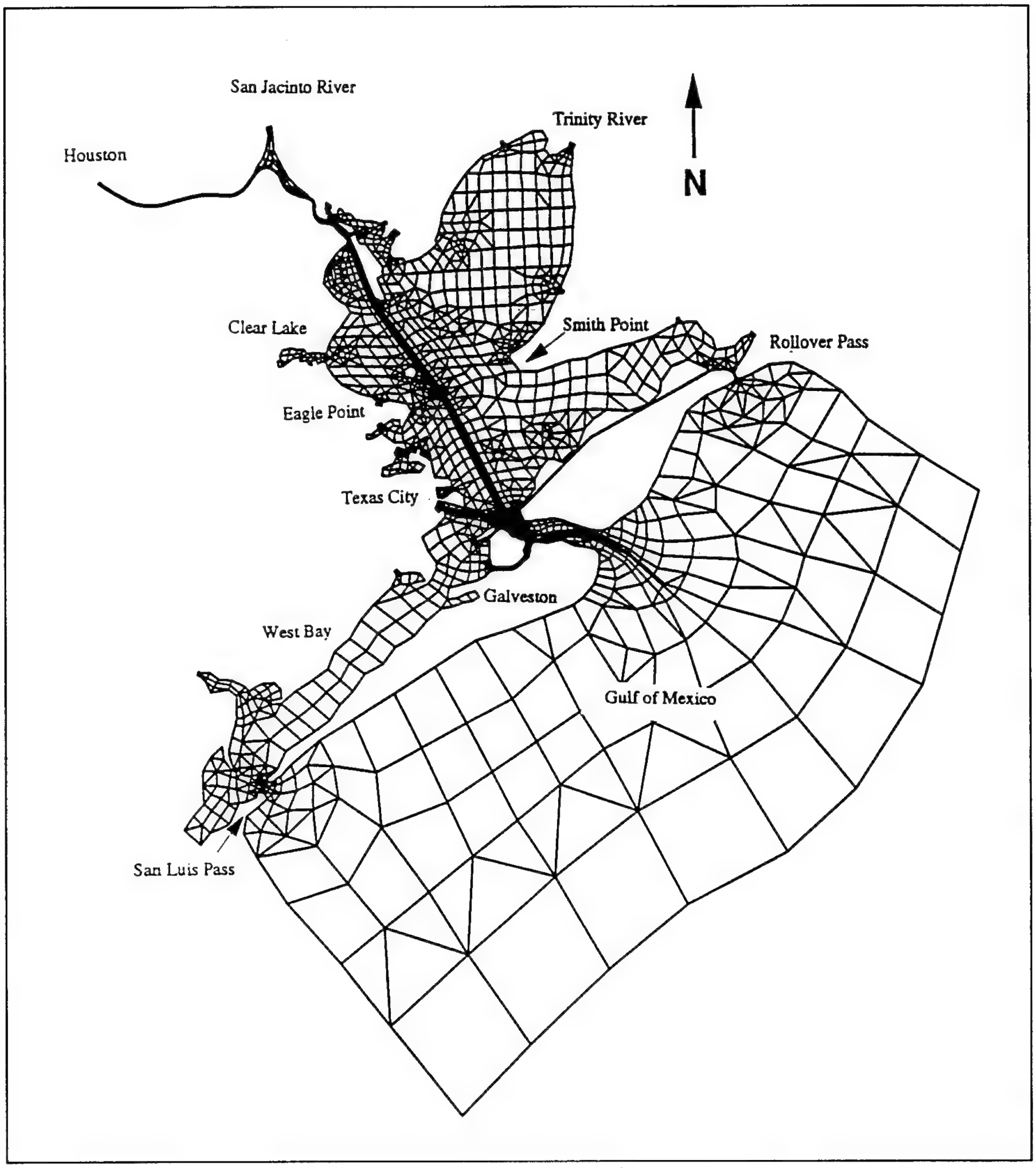


Figure 4. Phase II conditions

1991 (Figure 8). These data represent 3,105 days of recorded data during this time frame. Additionally, wind speed and direction were recorded for this period at sta S10.1 (Figure 9) and at Houston Intercontinental Airport. A full description of these data is presented in Fagerburg et al. (1994). Use of these data is discussed in Berger et al. (in preparation).

Geometric and bathymetric data for the bay were obtained from NOAA Charts numbered 11,323, 11,326, and 11,332. Additionally, existing channel

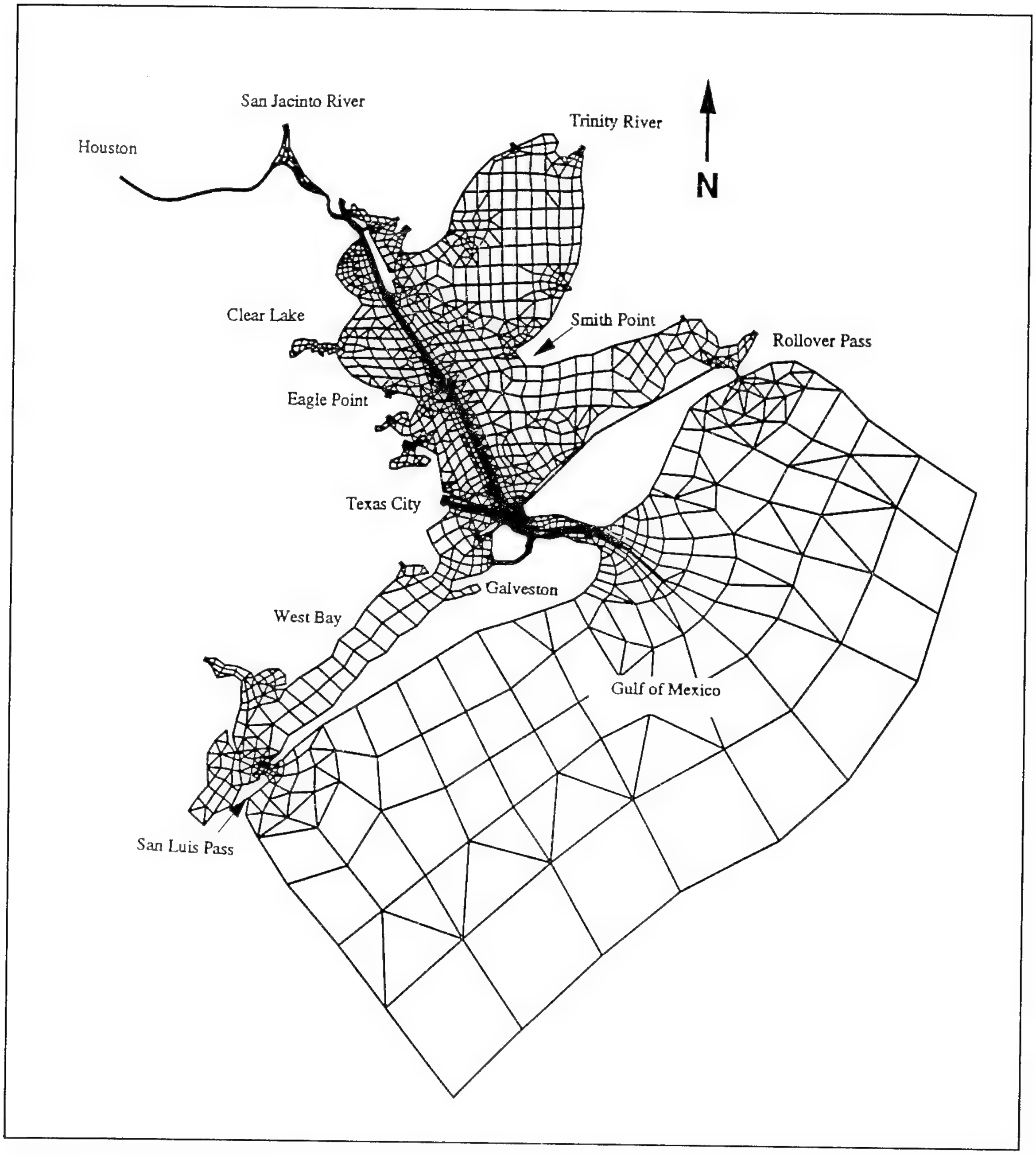


Figure 5. NED conditions

conditions were provided by the U.S. Army Engineer District, Galveston. The District also provided channel alignments, depths, and side slopes for the two deepening phases, some of which had been determined from the ship simulator effort covered in Hewlett (1994). Freshwater inflows for the various scenarios were developed jointly by the Galveston District and the Texas Water Development Board. These flows considered future water use, source of this water, known projects such as the Wallisville Dam on the Trinity River, and projected future interbasin water diversions.

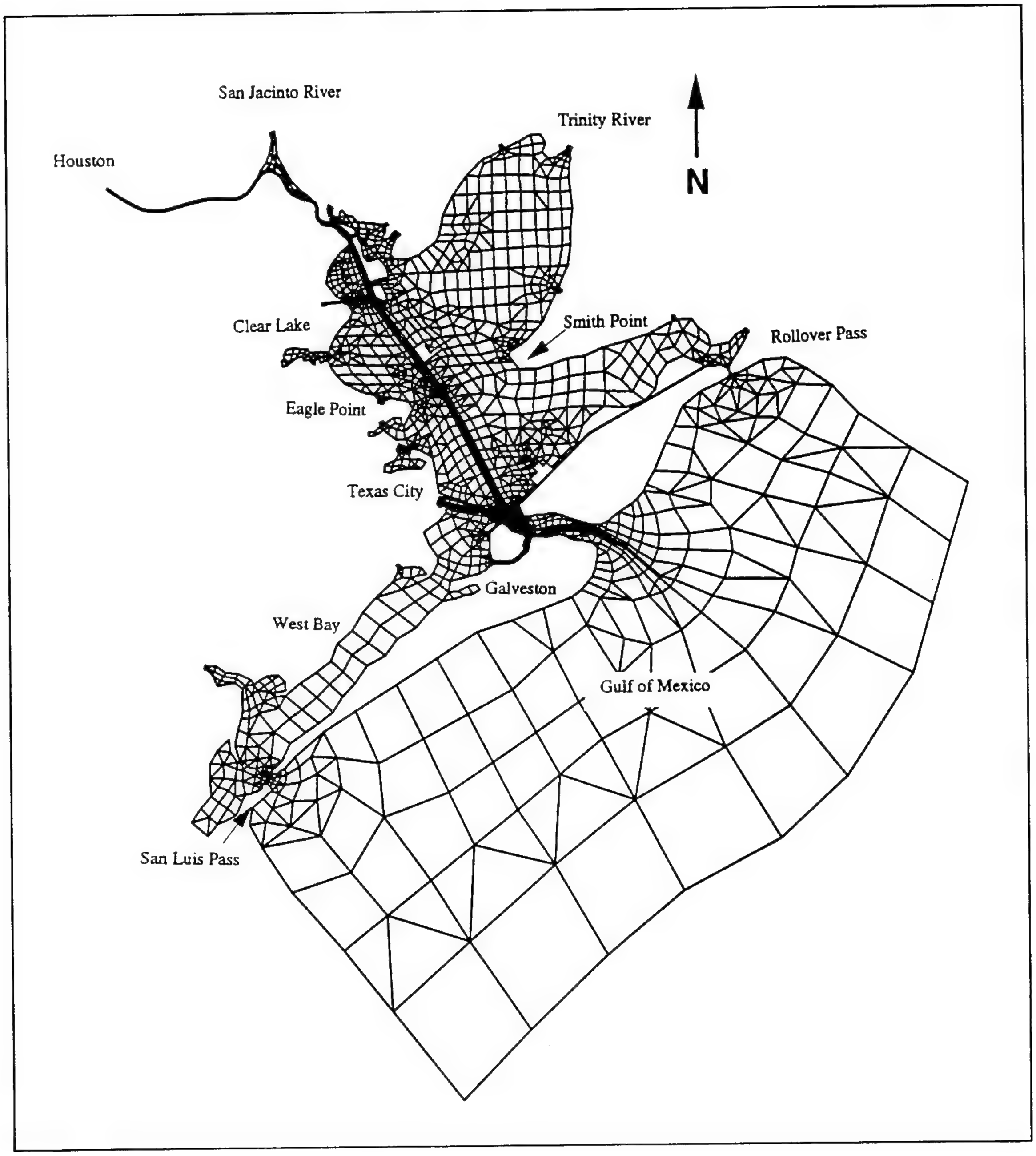


Figure 6. Mitigation conditions

Verification

The period of data collection was from 19 July 1990 to 15 January 1991. Data were collected by moored salinity and velocity meters, as well as tide gauges mounted throughout the system, during the bulk of this time. Within this 6-month period a short-duration intense field collection was conducted on

Figure 7. 2-D and 3-D delineation

19-20 July 1990. These data included velocity and salinity measurements over depth at five ranges along the navigation channel.

The basic philosophy adopted in the verification process was to make any appropriate adjustments to the model to reasonably match the short intense survey period, then make the long-term simulations unaltered and compare them to measured results as a check on the model's performance. This effort is fully reported in Berger et al. (in preparation).

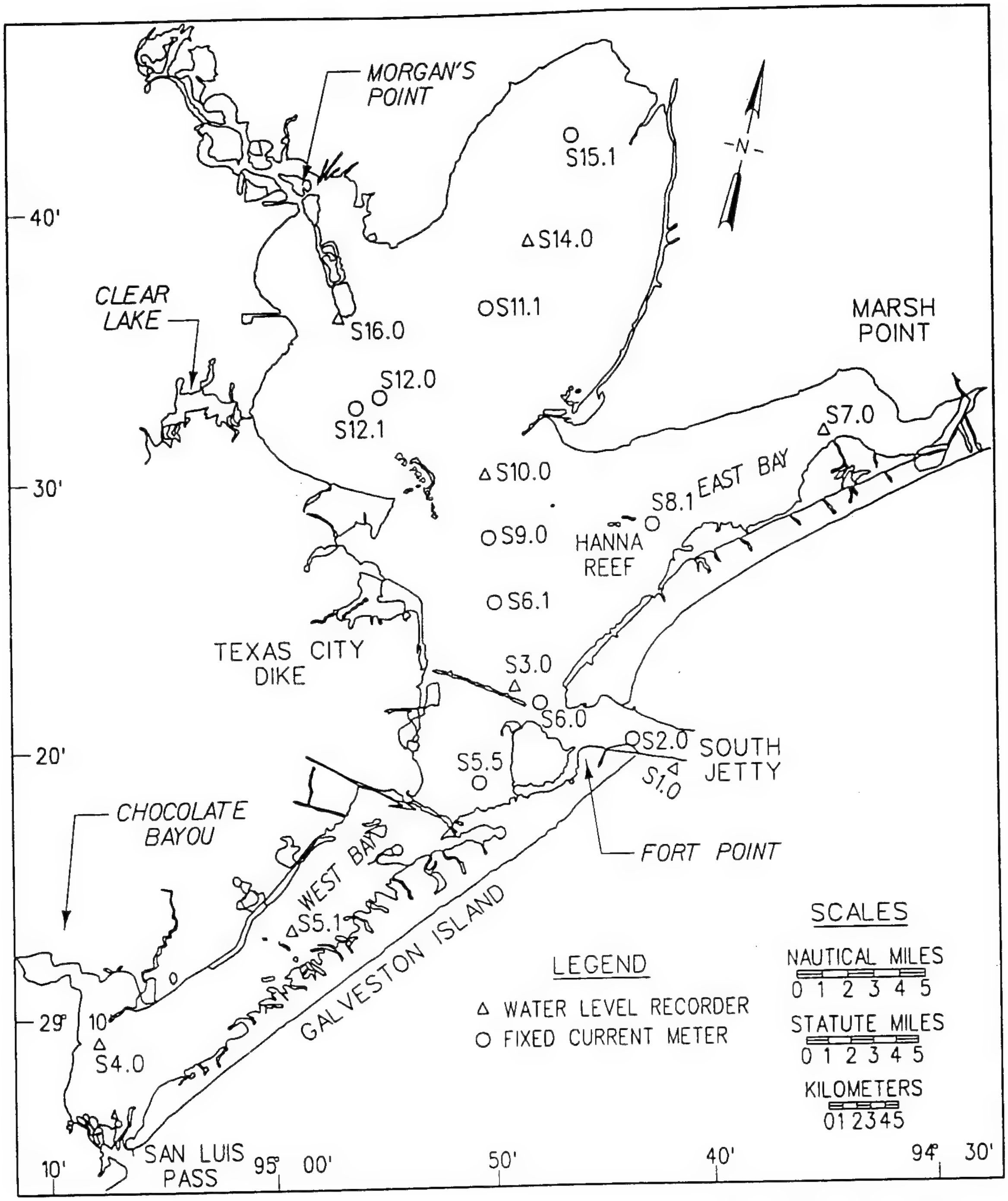


Figure 8. Basic long-term survey data equipment locations (stations S1.0, S2.0, S5.5, S6.0, S6.1, S8.1, S9.0, S11.1, S12.0, and S15.1 record salinity as well)

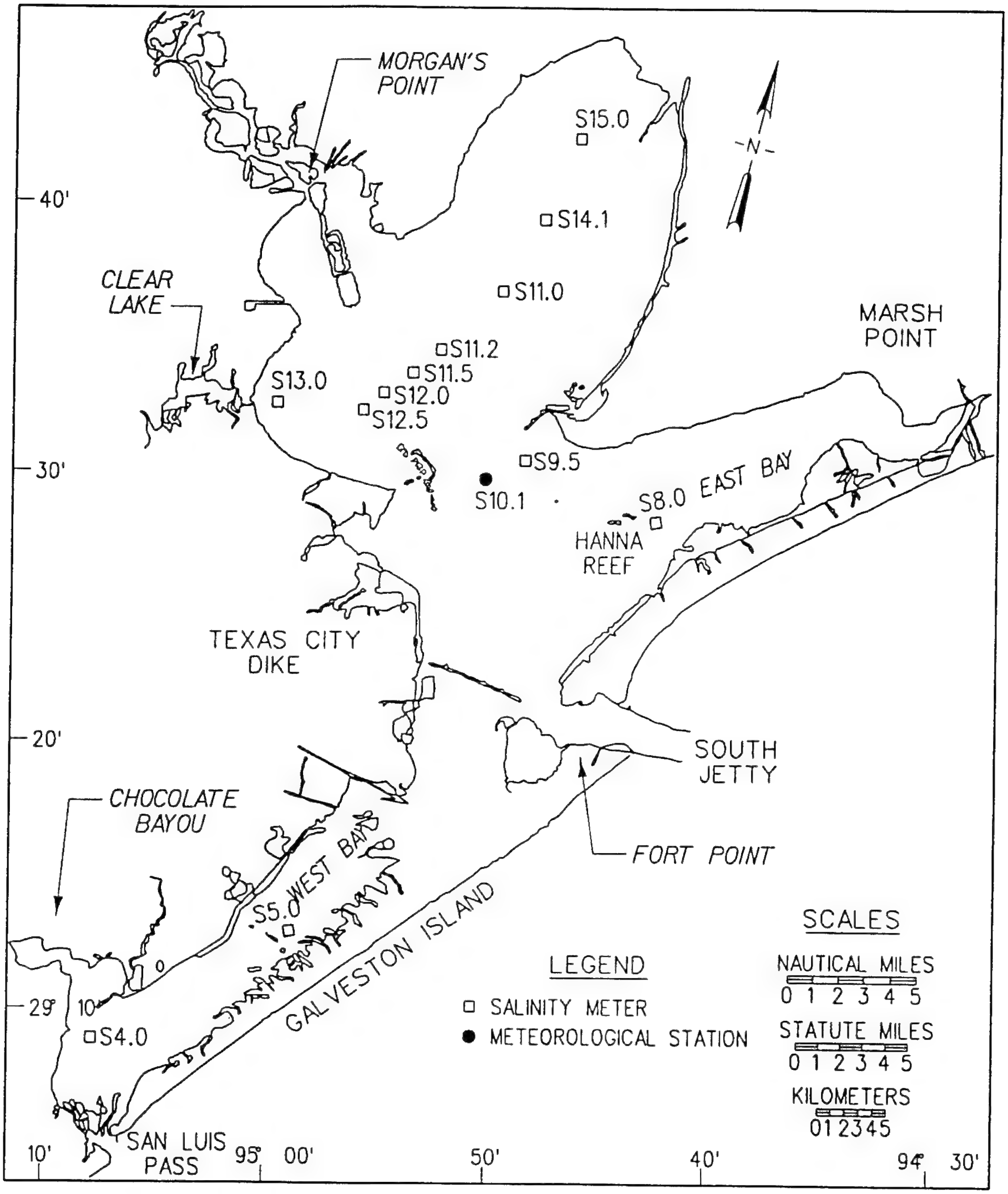


Figure 9. Supplementary long-term collection equipment location map

3 Testing and Results

Introduction

This chapter describes the basic test conditions, the manner in which the model was run, results, and discussion of these results. The basic test conditions consist of duration of simulation, the bathymetry/geometry, hydrology, and the tidal and salinity boundary.

A total of 60 possible scenarios was considered for RMA10-WES simulation. Five geometric conditions were evaluated, and each could be evaluated for four hydrologic conditions. These hydrologic conditions are each further subdivided into three representative flow levels. The five geometric conditions are as follows:

a. Existing channel.

b. National Economic Development Plan (NED) channel and dredged material disposal plan (the channel condition in the EIS).

c. Phase I channel improvements (45-ft depth) with intermediate dredged material beneficial use plan.

d. Phase II channel improvements (50-ft depth) with intermediate dredged material beneficial use plan.

e. Final mitigation (45-ft-depth) channel with final dredged material beneficial use plan.

The following four hydrologic conditions reflect projected future hydrologic and water use patterns considering planned reservoirs, water importation, groundwater usage changes, and population growth:

a. Present (year 1990).

b. Year 1999 (with proposed Wallisville saltwater barrier).

c. Year 2024.

d. Year 2049.

For all four hydrologic conditions, three time-varying freshwater inflow levels representing an annual sequence of high, median, or low inflow were considered. These flows are tabulated by location and month as acre-feet in Appendix B. A subset of all these possible scenarios was selected to produce a manageable analysis that would meet the objectives of this study.

The Gulf of Mexico salinity varies by season. Mississippi River outflow hugs the Texas coast and lowers salinities during certain seasons. The work of Cochrane and Kelly (1986) was consulted and 15-year monthly averages for Gulf salinity obtained. These were used for the Gulf boundary salinities for each month run in the model. These are shown in the following tabulation:

Month 1957-1971	Average Monthly Salinity, ppt
January	29.1
February	29.1
March	28.4
April	26.2
May	24.9
June	28.1
July	31.6
August	33.3
September	28.7
October	28.5
November	29.5
December	29.4

Boundary Conditions

The series of tests simulated in the model are shown in the following tabulation.

These runs produced salinity values over the 9-month period for a select number of locations, based upon the hydrodynamic model runs at other flow hydrologies. This approach is covered in Hsieh (in preparation), and the results of those runs presented in that report.

The period of primary interest for oysters and other species is the summer months. Thus, the Y-runs were considered to be long enough to provide data

Geometry/Bathymetry	Hydrology											
	Present			1999			2024			2049		
	L	M	H	L	M	H	L	M	H	L	M	H
Existing	X	X	X	Y	S	-	Y	Y	Y	Y	Y	Y
Phase I	X	X	X	Y	S	-	Y	Y	Y	Y	Y	Y
Phase II	-	-	-	-	-	-	Y	Y	Y	Y	Y	Y
NED	-	-	-	-	-	-	Y	-	-	-	-	-
Mitigation	-	-	-	-	-	-	-	X	-	-	-	-

Note: X = runs 1 year long, January-December.
Y = runs 9 months long, January-September.
S = runs generated using systems model approach.

for oyster model results for 9-month runs and 12 months of data from the X-runs.

The various hydrologic eras represent predicted water use and hydrologic patterns expected over the life of the project. These are described in U.S. Army Engineer District, Galveston (1987), Texas Water Development Board (1990), and Metcalf and Eddy with Ekistics Corporation (1989). The 1999 era includes the Wallisville saltwater barrier project on the Trinity River and the redistribution of flows accompanying the release operations. The 2024 era represents a time in which the projected growth of the Houston metropolitan area forces a diversion of water from the Trinity River to the city and ultimately into Galveston Bay. This is generally regarded as the era that represents a worst case for the bay system. The 2049 era is at the end of estimated project life. With the continued projected growth of the Houston area, additional flow is diverted into the Galveston Bay system from rivers or water sources outside the Galveston Bay watershed; i.e., it is projected that there will be more fresh water flowing into the Galveston system than in 2024. The low, medium and high are typical flow years of that nature in the projected year 2049. These inflows were synthesized by the Texas Water Development Board and Galveston District to reflect projected typical low-, medium-, and high-flow years in the various eras. The data are given as monthly averages and depicted in Figure 10.

Two Houston Power and Light Company electric power generation plants were included in the model: the Cedar Bayou and Robinson plants. Monthly power plant intake rates for the year 1990 were used for all testing. The model used the salinity values obtained at the intake as the specified boundary condition at the discharge.

Flows from Buffalo Bayou, San Jacinto River, and Trinity River were enforced as specified discharge boundary conditions across particular boundary nodes with a salinity value of zero concentration. On the small streams, Chocolate, Highland, Oyster, Robinson, Cedar, Dickinson, and Live Oak

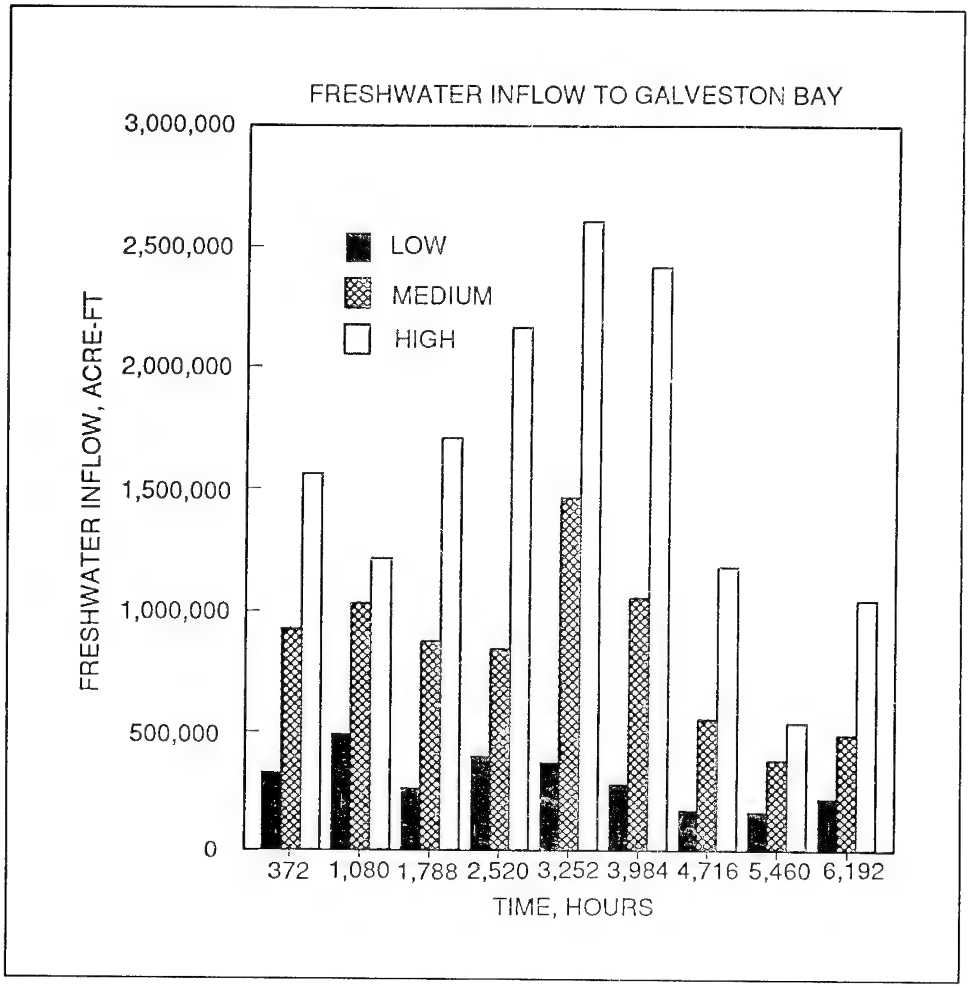


Figure 10. Total freshwater inflows

Bayous and Clear Creek, the flow rates are so small, on the order of 200 cfs, that if one implemented a zero salinity boundary condition specified at these boundary nodes, the fluid nearby would not be significantly diluted. An extraordinary amount of resolution would then be required to resolve these gradients. Instead the flow was added to appropriate elements in the same manner as one would input rain, for example. This allowed the area to be diluted without requiring excessive resolution.

The freshwater inflows, power plant intake/discharge, and salinity boundary data were updated every day in the simulation. To prevent extremely rapid variation in these values, a 9-day moving average was used to slightly smooth the data. This was particularly important in the freshwater inflows since they were given only as monthly values and changes between months could have been large.

The tidal boundary data were from NOS/NOAA station 877-1510 at Pleasure Pier for calendar year 1984. This year was found to be a typical

temperature year, which was felt to be appropriate for the oyster modeling work. The model boundary, which is offshore about 26 miles, used these data shifted forward in time by 1.31 hr. This matched the phase at Pleasure Pier. Periods of less than 3 hr were removed by filtering, preventing noise in the results.

The 1984 wind data were obtained from the National Weather Service for Houston Intercontinental Airport. From a correlation with data collected at sta S10.1 in Galveston Bay during the verification period, these wind data were transposed to the bay system.

Test Procedures

The original boundary condition information was produced on a daily basis for all freshwater inflows and power plants. The wind magnitude and direction, tide elevation, and salinity were hourly. The largest time-step taken was 1 hr. If the convergence suggested that smaller time-steps should be run, the boundary data were interpolated to either half- or quarter-hours, as necessary, and half- or quarter-hour time-steps were run. The problem solved was nonlinear in that several of the unknown variables were written as products. Thus a system to linearize the problem and iterate each time-step to final solution was required. The method chosen was the Newton-Raphson method. The number of iterations in the Newton-Raphson scheme was either 3 or 4, as needed. Most of these procedures were automatically implemented by the model or the scripts (computer-run control programs) that ran the model.

Hot-start files were generated regularly, which consisted of all values at the computational nodes at a point in time. This file could then be run to restart the model "hot," which requires no spin-up time and basically picks up where the previous run ended. A file of select nodal data at all depths was saved and plotted for quality control, and all hydrodynamic and salinity data were saved on file for eventual export for use in the oyster model.

Results

Time-series

The time-series results for Phase I versus existing bathymetry (present hydrology, 1990) flow are shown in Plates 1-48. The bottom salinity results for low flow are in Plates 1-16, medium flow in Plates 17-32, and high flow in Plates 33-48. The overall trends are as noted in the section, "Isohaline plots," with the most significant salinity changes occurring in the upper bay west of the channel. The time-series results yield information about the time distribution and duration of the salinities at particular locations, shown in Figure 11.

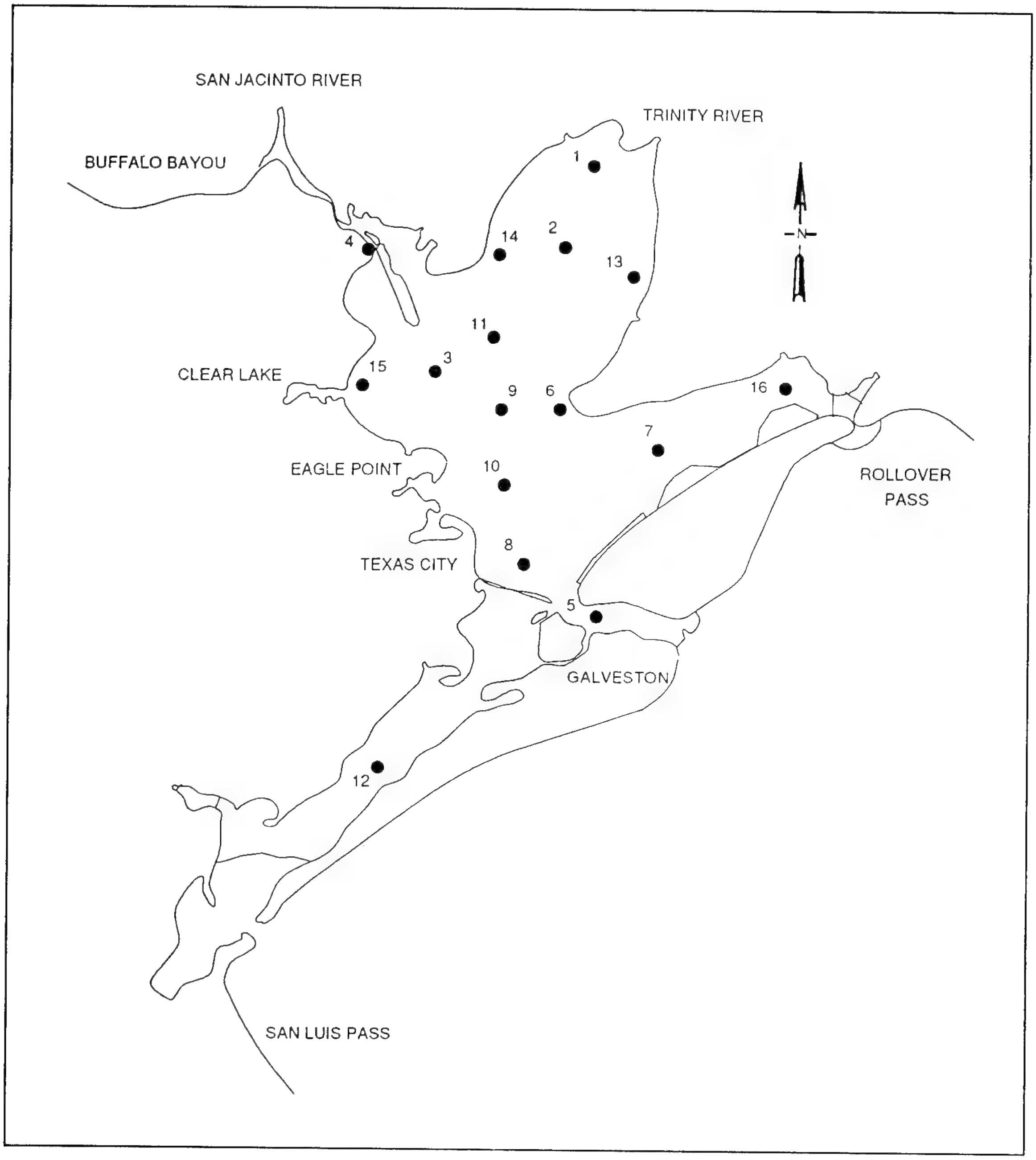


Figure 11. Time-series points

Table 2 summarizes all of the time-history data grouped into 2-month segments (April-May, June-July, August-September, October-November). The values given are in terms of the average salinity increase: a value of -1, for example, indicates the plan showed an average decrease in salinity between 0 and 1 ppt. A value of 0 means increases between 0 and 1 ppt, a value of 1 indicates the increase is between 1 and 2 ppt, etc. Essentially, this amounts to rounding down to the nearest integer value of salinity change. The periods of less than 14 days (350 hr) have been removed by filtering. As a result of

Table 2
Summary of Time-History of Salinity Change Results, 2-Month Averages, Bottom Elevation

Hydrology	Months	Salinity, ppt					
		Trinity Point 2	Channel Point 3	East Bay Point 7	South West Point 8	West Bay Point 12	Upper West Point 15
Phase I							
1990 Low	Apr-May	2	2	1	0	1	3
	Jun-Jul	1	2	0	-1	0	2
	Aug-Sep	1	3	0	0	0	2
	Oct-Nov	2	2	1	1	0	2
1990 Med	Apr-May	0	3	0	0	0	3
	Jun-Jul	0	2	-1	-1	0	2
	Aug-Sep	1	3	0	0	0	2
	Oct-Nov	1	3	1	1	1	3
1990 High	Apr-May	0	2	0	0	1	1
	Jun-Jul	0	2	0	-1	1	0
	Aug-Sep	2	5	1	0	1	3
	Oct-Nov	2	4	1	1	1	3
1999 Low	Apr-May	0	1	0	0	0	2
	Jun-Jul	0	2	0	-1	0	1
	Aug-Sep	1	3	1	0	0	2
2024 Low	Apr-May	0	1	0	0	0	2
	Jun-Jul	0	1	0	0	0	1
	Aug-Sep	1	2	0	0	0	2
2024 Med	Apr-May	0	2	0	0	1	2
	Jun-Jul	0	1	0	-1	0	1
	Aug-Sep	-1	1	-1	-1	-1	1
2024 High	Apr-May	0	1	0	0	0	1
	Jun-Jul	0	0	-1	-2	0	0
	Aug-Sep	0	2	-1	-1	-1	1
2049 Low	Apr-May	2	2	1	0	0	3
	Jun-Jul	1	2	0	0	0	2
	Aug-Sep	1	2	0	0	0	2

(Continued)

Table 2 (Concluded)							
		Salinity, ppt					
Hydrology	Months	Trinity Point 2	Channel Point 3	East Bay Point 7	South West Point 8	West Bay Point 12	Upper West Point 15
Phase I (Continued)							
2049 Med	Apr-May	0	2	0	0	0	2
	Jun-Jul	0	1	0	-1	0	1
	Aug-Sep	0	3	0	0	0	2
2049 High	Apr-May	0	1	0	-1	1	1
	Jun-Jul	0	1	0	-1	0	0
	Aug-Sep	0	2	0	0	0	2
NED							
2024 Low	Apr-May	0	2	1	0	0	3
	Jun-Jul	1	2	1	0	0	2
	Aug-Sep	1	2	1	1	0	3
Phase II							
2024 Low	Apr-May	1	3	1	0	1	3
	Jun-Jul	2	3	1	0	0	3
	Aug-Sep	2	3	1	0	1	4
2024 Med	Apr-May	0	3	1	1	1	3
	Jun-Jul	0	4	1	1	1	4
	Aug-Sep	1	3	0	0	0	3
2024 High	Apr-May	0	3	0	0	2	2
	Jun-Jul	0	2	0	-1	1	1
	Aug-Sep	1	3	-1	0	0	3
2049 Low	Apr-May	0	2	0	0	-1	3
	Jun-Jul	1	3	0	0	0	3
	Aug-Sep	1	2	0	0	0	2
2049 Med	Apr-May	0	3	0	0	1	3
	Jun-Jul	0	2	0	0	0	2
	Aug-Sep	1	4	1	1	1	4
2049 High	Apr-May	0	2	0	0	1	2
	Jun-Jul	0	3	0	0	1	1
	Aug-Sep	1	4	0	0	1	4

the filtering process the first and last 28-day periods show an artificial bulge, and therefore these were not included in Table 2.

The typical Galveston Bay trend is for low salinity values through early summer. The large drop in freshwater inflow beginning in July along with the higher Gulf salinity causes a rise in salinity, usually reaching a maximum around October. The model Gulf salinity drops quickly in September and the bay salinities follow later. The response to the freshwater changes are, of course, more pronounced for the high-flow run than at lower flow conditions.

The overall increase in salinity of the Phase I deepening in comparison to the existing conditions was regionally most noticeable in the upper bay and in the fall for all regions. During high freshwater flow periods, this region and Trinity Bay were practically fresh for both existing and Phase I. Generally, the maximum increase in salinity was greater during the high-flow scenario than in the low. The salinity gradient from the channel to the bay surrounding it was larger as a result of the deepening. The increase in the lower bay was much smaller than in other areas, typically about 1 ppt.

Considering first the medium-flow conditions, the Trinity Bay area (points 1, 2, 13 and 14) shows a small increase in maximum salinity in the late summer and fall on the order of 1 or 2 ppt. During the high-flow period in late spring and early summer the difference was less. The upper bay (points 3, 4 and 15) shows the most dramatic increase; in fact, point 15 has only about 2 months when the salinity was less than 10 ppt versus a 6-month period for the existing conditions. The maximum increase in salinity for this location was on the order of 5 ppt occurring in the fall. The largest change for the midbay (locations 6, 9, and 10) was an increase of about 2 ppt in the fall. East and West Bays (locations 7 and 12, respectively) are only slightly affected by the deepening with West Bay showing about a 1-ppt increase in late summer and fall. The lower bay (location 8) in the early summer actually shows a slight decrease in salinity due to Phase I. The channel is somewhat more stratified with the enlarged channel perhaps leading to less saline flows leaving the channel in the lower bay.

The low flow shows a more uniform plan impact over the year, and conversely the high flow shows a less uniform change. The upper bay does slightly exceed 20 ppt for Phase I, whereas the base existing conditions are about 17 or 18 ppt throughout the fall. The increase due to the plan is generally greater in the high-flow year than in low; thus, the range of variation from low to high is less with the Phase I condition. These are shown in Plates 49-160, respectively. The salinity time-series for NED and Phase II are shown in Plates 161-176 and 177-272.

These future year hydrology scenarios for 2024 and 2049 were tested for a low-, medium-, and high-flow condition and for 9 months (January-September). These tests were conducted for existing and for Phase I and II bathymetry/geometry. The future year hydrology indicated as 1999 was tested

for the same 9-month period for low-flow conditions and existing and Phase I bathymetry/geometry.

The change in salinity between Phase I and existing bathymetry/geometry appears to be less significant in all future hydrologic scenarios (1999, 2024, and 2049). In all these hydrologies, the flow distribution increases flow from Buffalo Bayou and the San Jacinto Rivers and reduces flow from Trinity River. So the Trinity Bay area has increased salinity under existing bathymetry. The additional flow to the west side of the bay produces a decrease in salinity there. The deepened channel results in less increase in salinity in the future hydrologies.

The salinity increases are greatest for the 2024 Phase II scenario. These are larger than the 1990 Phase I scenario reported previously. In 2024 the distribution of change is similar to that reported previously, though the difference is noticeable throughout the spring and summer. The overall differences for the year 2049 were much less; in fact, they appear to be less than for the Phase I conditions under 1990 hydrology. In the lower bay it is interesting that for a period of time in the spring the existing condition has a higher salinity than Phase II. This has been noted in earlier studies (Berger and Boland 1979) in bay regions away from the channel. It is likely that the deepened and more flood dominant channel allows less fresh water to exit Galveston Bay through the channel and thus forces the fresh water through the bay. The channel is also slightly more stratified under deepened conditions. During the period of salinity rebound, the salinity in the lower bay appears to react more slowly, perhaps due to the presence of more stratification. It may be that more salt is carried in the channel past the lower bay rather than immediately raising lower bay salinity.

Isohaline plots

The data were further presented as isohaline (lines of equal salinity) plots. In Plates 273-308, the lines depict equal salinities for the existing versus Phase I bathymetries in 5-ppt intervals. The low-flow case is shown in Plates 273-284, medium flow in 285-296, and high flow in 297-308. Generally speaking, the deepened channel in the Phase I bathymetry shifts the isohalines further up the channel and deeper into Trinity Bay, with the August-October shifts being the most pronounced. The medium- and high-flow cases indicate similar patterns for both bathymetries as depicted for the low flow for the months of January through September. Larger differences are observed for October through December.

The existing versus Phase I case for 1999 hydrology is shown in Plates 309-317; this is a low-flow scenario. The existing versus Phase I cases are shown for low (Plates 318-326), medium (Plates 327-335), and high (Plates 336-344) fresh water, 2024 hydrology. These show a comparison between plan and existing that is much closer than for the 1990 hydrology. For the low- and medium-inflow conditions the most notable differences are in

the upper west side of the bay beginning in May and continuing through September. For the high-flow condition these differences begin in August.

The existing versus Phase I cases are shown for low (Plates 345-353), medium (Plates 354-362), and high (Plates 363-371) fresh water, 2049 hydrology. These results are quite similar to the 2024 hydrology.

The existing versus Phase II cases are shown for low (Plates 372-380), medium (Plates 381-389), and high (Plates 390-398) freshwater inflow, 2024 hydrology. These depict slightly increased salinity intrusion for the months January through May, and larger increases for the drier months of June through September. The pattern is similar to the existing hydrology, Phase I comparison to the base condition. This low-flow hydrology also represents the lowest of the low-flow hydrologies tested, and thus should represent the "worst case" as far as salinity intrusion results, as comparison to Plates 318-344 indicates.

The existing versus Phase II cases are shown for low (Plates 399-407), medium (Plates 408-416), and high (Plates 417-425) freshwater inflow, 2049 hydrology. These depict improved conditions when compared to the 2024 cases, and are very similar to the results for Phase I, 1990 hydrology. This can be seen by comparing Plates 399-425 with Plates 345-371.

Mitigation plan

The channel configuration for this test is identical to the Phase I project, except for the addition of the Bayport Channel and a small channel through Atkinson Island, and the final Beneficial Uses Group dredged material placement plan was used instead of the preliminary plan, which consisted of the 17 islands. The conditions under which this bathymetry was tested were for the 2024 year hydrology distribution for a typical medium freshwater inflow condition. This run was for 1 year. As expected, these results are very much like the Phase I results for the same hydrology and inflow; therefore, the mitigation plan will have no greater impact on salinities than Phase I.

4 Summary and Conclusions

In this report the results of extensive model testing of a proposed enlargement of the Houston-Galveston Navigation Channels through Galveston Bay, Texas, are presented. The present channel project depth is 40 ft and the deepened project depths are 45 ft (Phase I) and 50 ft (Phase II). Several flow distributions within the basin were tested. These are referred to as the 1990, 1999, 2024, and 2049 year hydrologics. Within each of these, a typical low-, medium-, and high-flow year was developed. The future hydrologic years represent predicted redistribution or increase of freshwater flow within the basin. The 1999 year is a result of flow redistribution that might be expected from implementation of the Wallisville Dam. The years 2024 and 2049 represent the increased water demand of the city of Houston, the results of which are for more fresh water to enter the bay via Buffalo Bayou and the San Jacinto River.

Results of testing for the 45-ft channel showed that largest increases in salinity were in low-salinity areas, including the upper west side of the bay across the channel from Atkinson Island, and the upper bay channel. Trinity Bay showed a small salinity increase. South of a line from Smith Point to Eagle Point the increase was generally less than 1 ppt. Some locations in the south bay near the navigation channel occasionally showed a decrease in salinity for the deeper channel configuration. These decreases occurred during the period of rebound in salinity after the high inflow period of late spring.

The 50-ft channel results were similar, qualitatively, to those of the 45-ft channel. However, the increases in salinity relative to existing channel conditions were larger.

The deepened channels showed increased salinity stratification. The stratification increased with channel project depths and with freshwater inflow in the Buffalo Bayou/San Jacinto River Basin. The slight decrease in salinity under deepened channel conditions in the southern part of the bay is probably a result of this increased stratification. The higher salinity may be propagating up the channel rather than spilling out into the adjacent lower bay.

The 1999, 2024, and 2049 hydrologic years result in more freshwater inflow to Galveston Bay through the Buffalo Bayou and San Jacinto River. The deepened channel typically resulted in less significant salinity increases in

these future scenarios than for the 1990 year. These future scenarios redistribute some of the freshwater inflow from the Trinity River and reintroduce it through Buffalo Bayou and San Jacinto River. The model shows a corresponding increase in salinity in Trinity Bay and decrease in the wester upper bay salinity.

The mitigation plan was the same channel geometry as that of Phase I but with fewer and a different arrangement of disposal islands. The tests indicated that the results were quite similar to those of Phase I.

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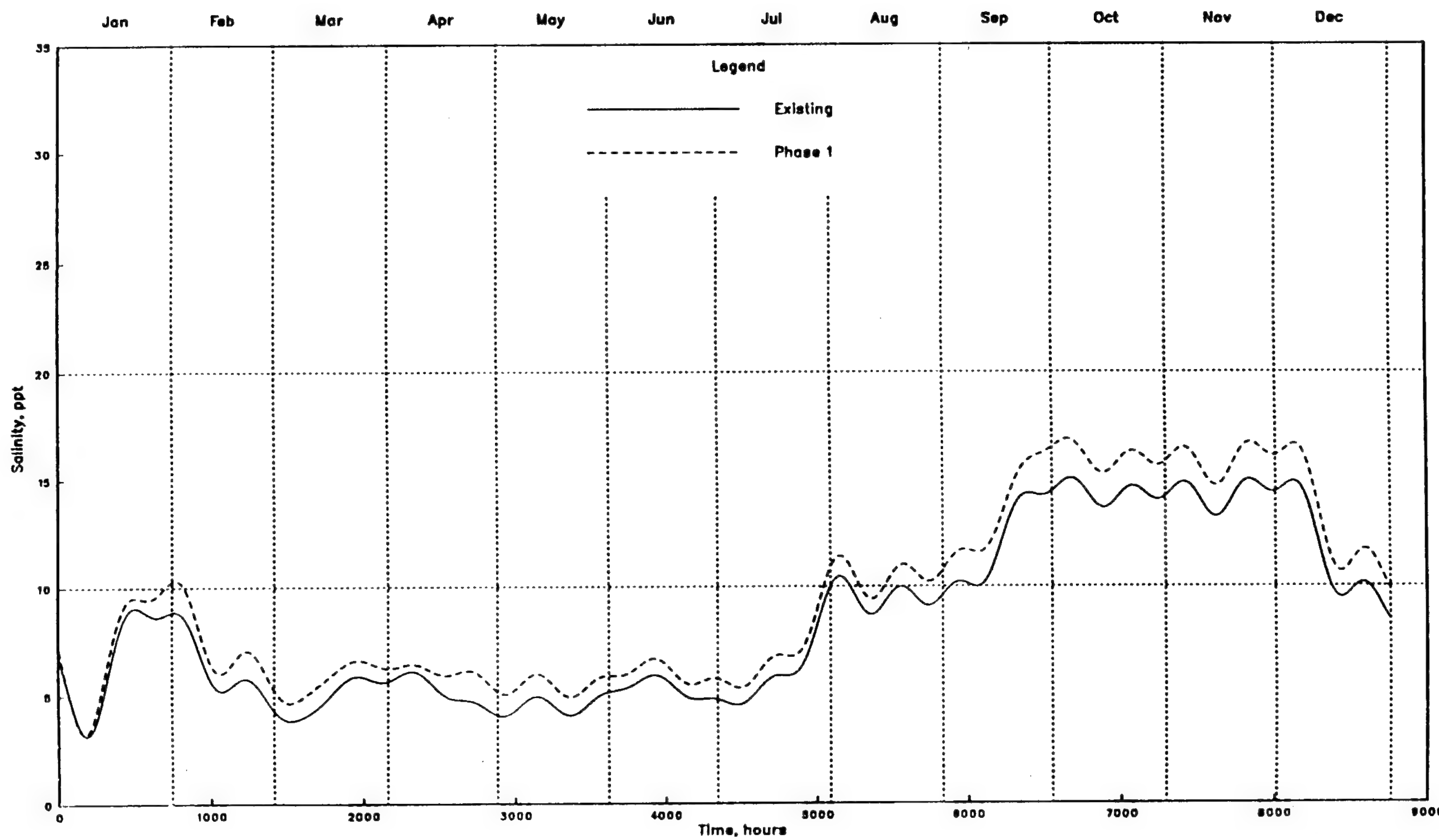
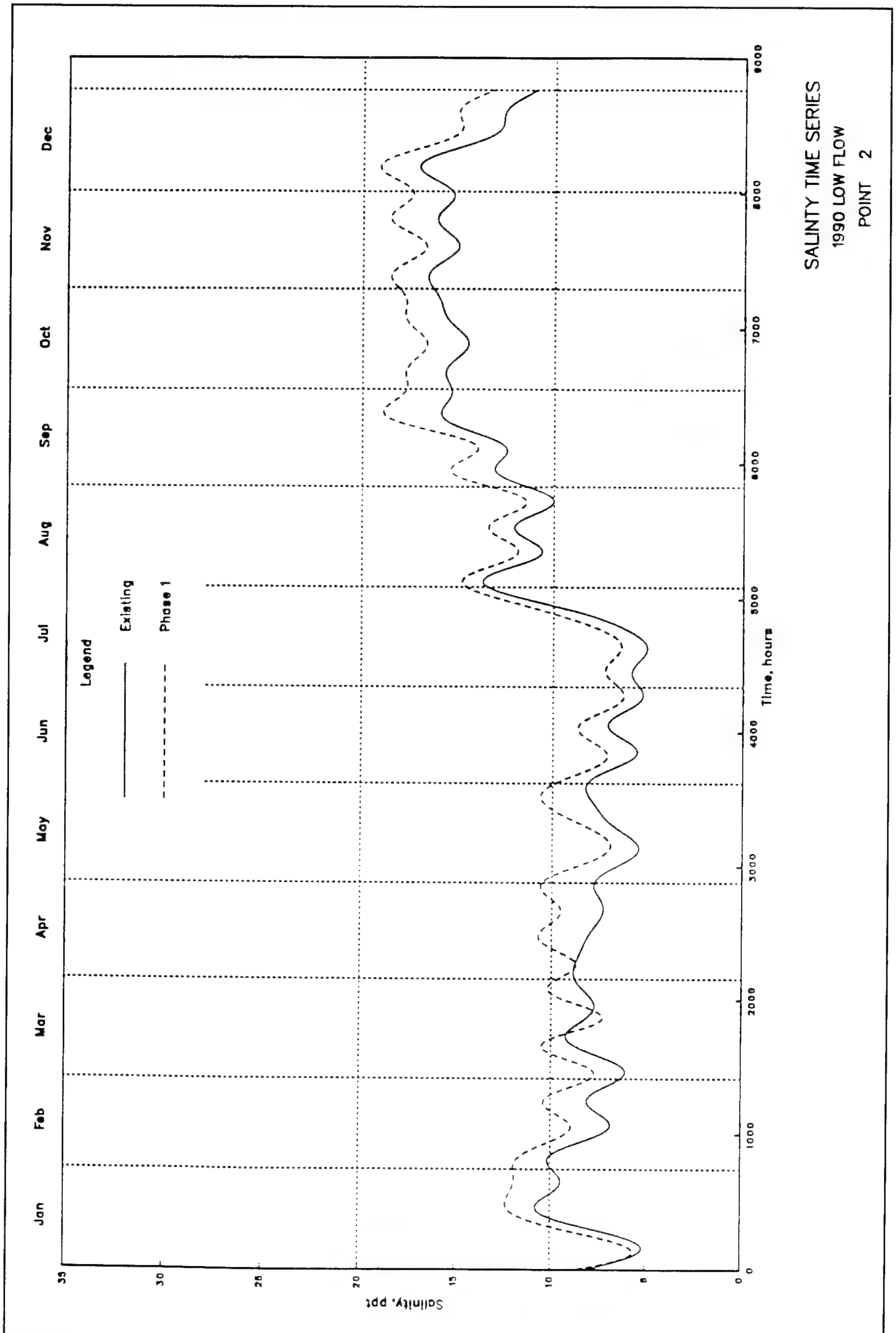


SALINTY TIME SERIES
1990 LOW FLOW
POINT 1

Plate 1


SALINTY TIME SERIES
1990 LOW FLOW
POINT 2
Legend
Existing
Phase 1
Jan
Feb
Mar
Apr
May
Jun
Jul
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Sep
Oct
Nov
Dec
Time, hours
0
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2000
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4000
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8000
9000
Salinity, ppt
0
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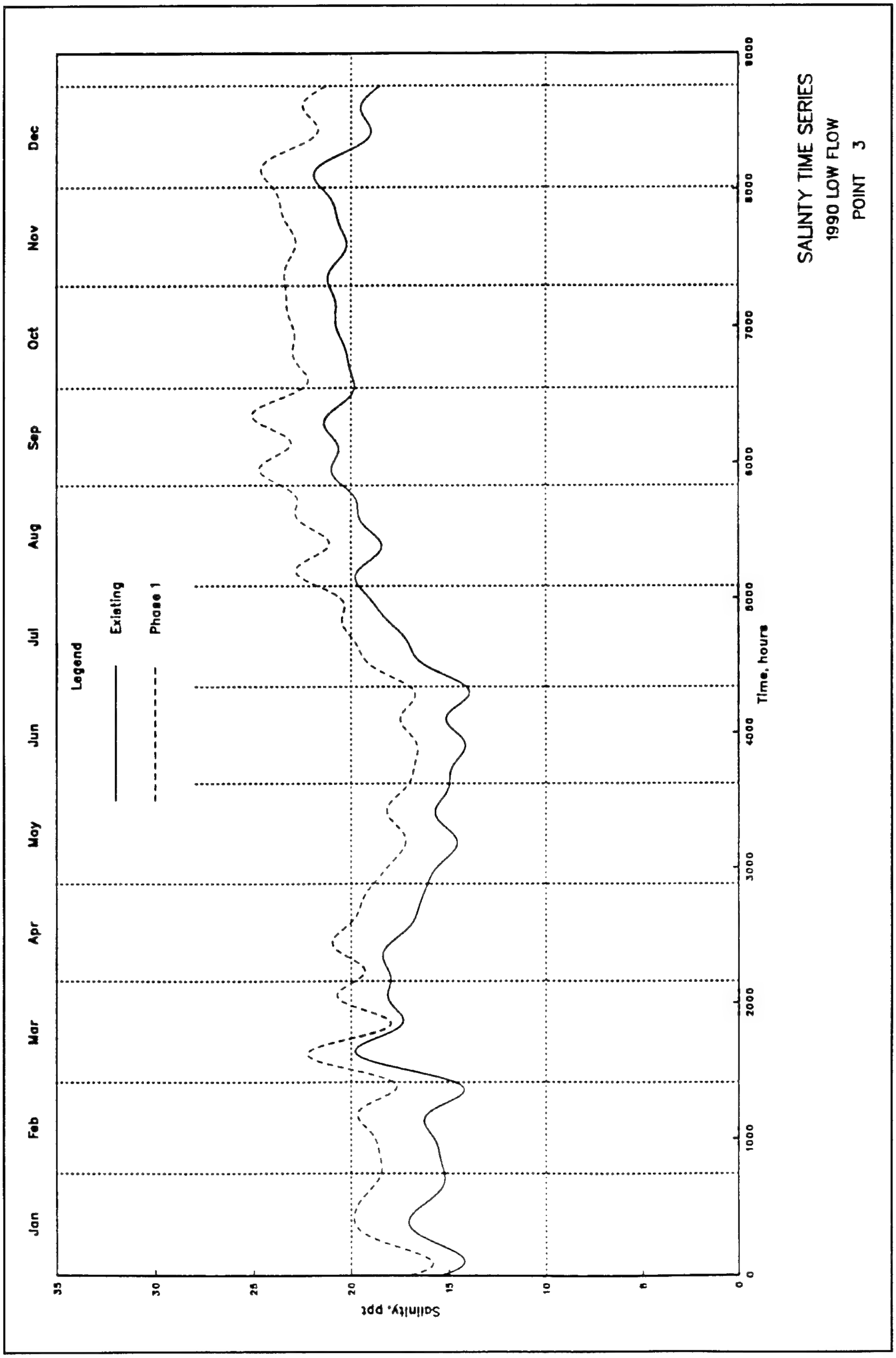
15
20
25
30
35

Plate 2


SALINTY TIME SERIES
1990 LOW FLOW
POINT 3
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
Jan
Feb
Mar
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Jun
Jul
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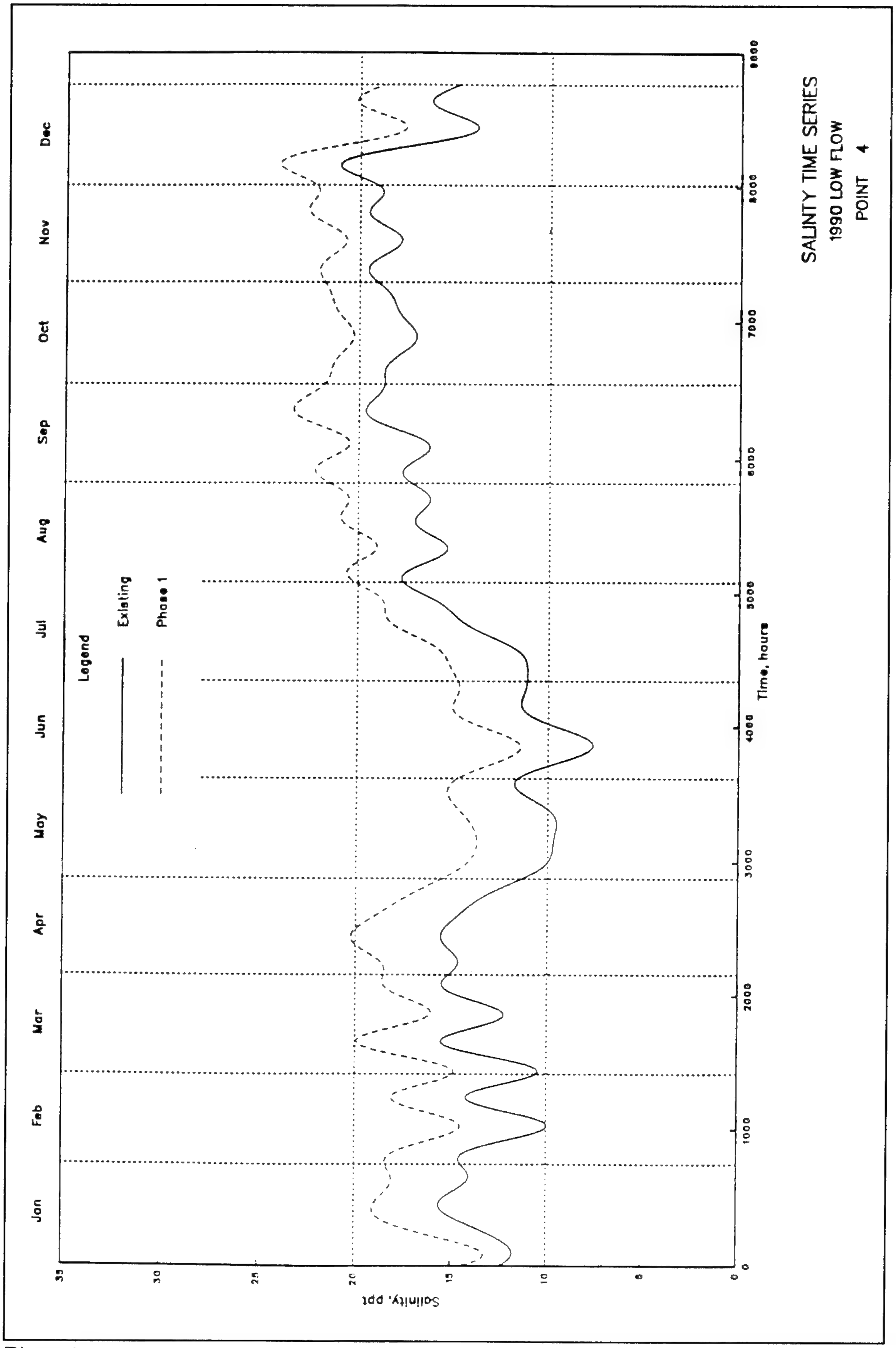
Plate 3



SALINTY TIME SERIES
1990 LOW FLOW
POINT 4
Legend
Existing
Phase 1
Jan
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Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Time, hours
Salinity, ppt
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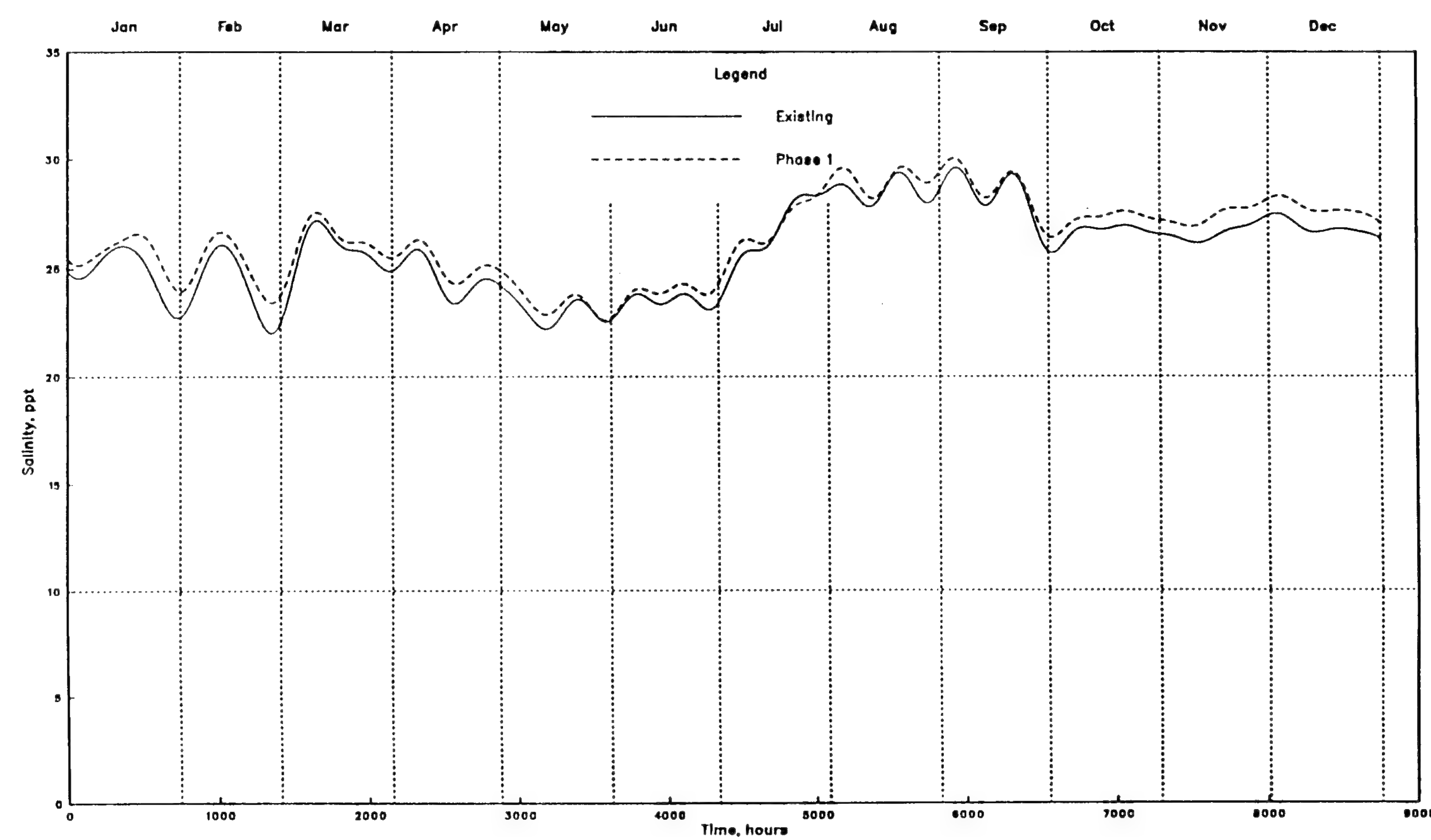
Plate 4

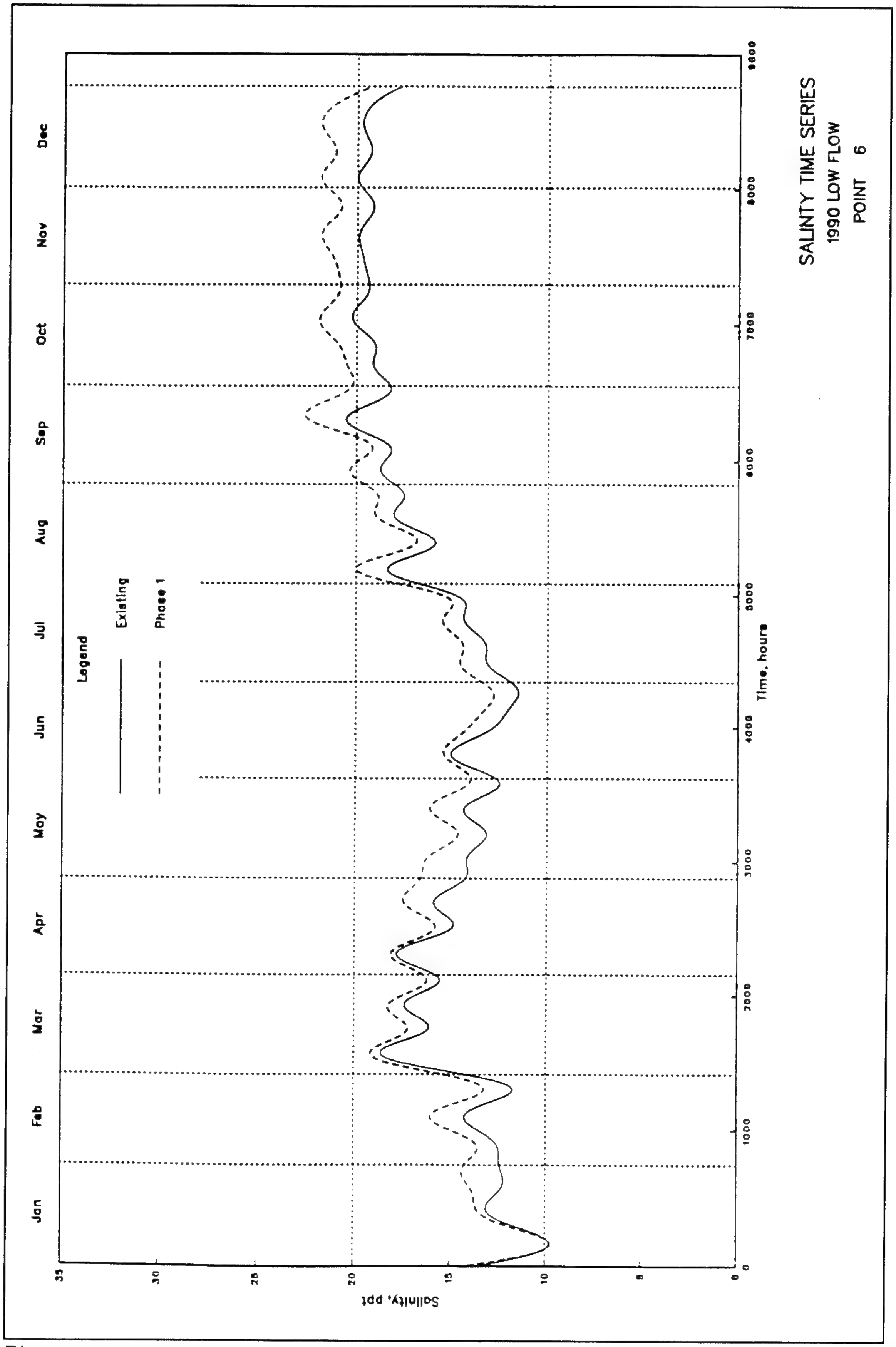


SALINTY TIME SERIES

1990 LOW FLOW

POINT 5

Plate 5


SALINTY TIME SERIES
1990 LOW FLOW
POINT 6
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
Jan
Feb
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Apr
May
Jun
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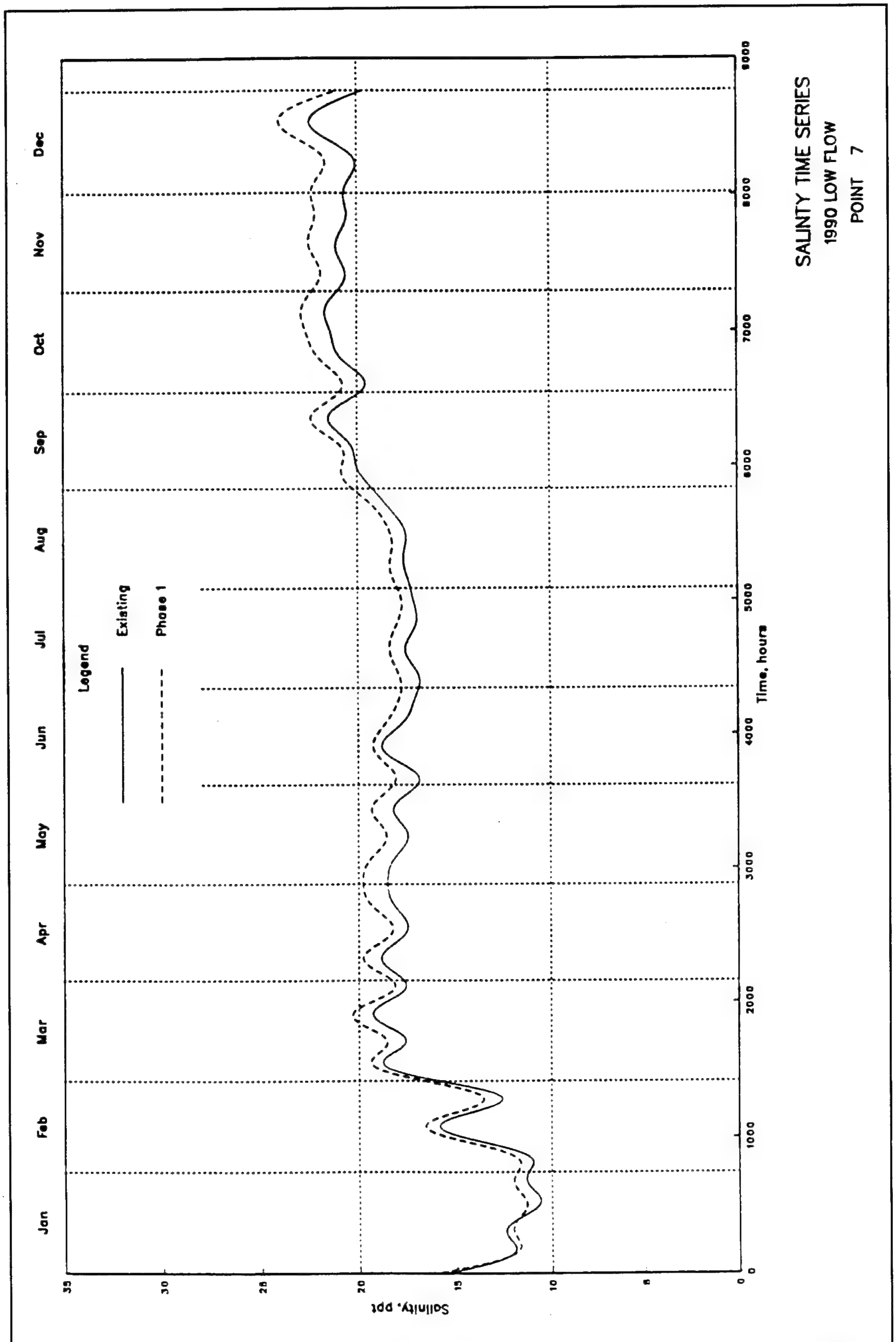
9000

Plate 6


SALINTY TIME SERIES
1990 LOW FLOW
POINT 7
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
Jan
Feb
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May
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Plate 7

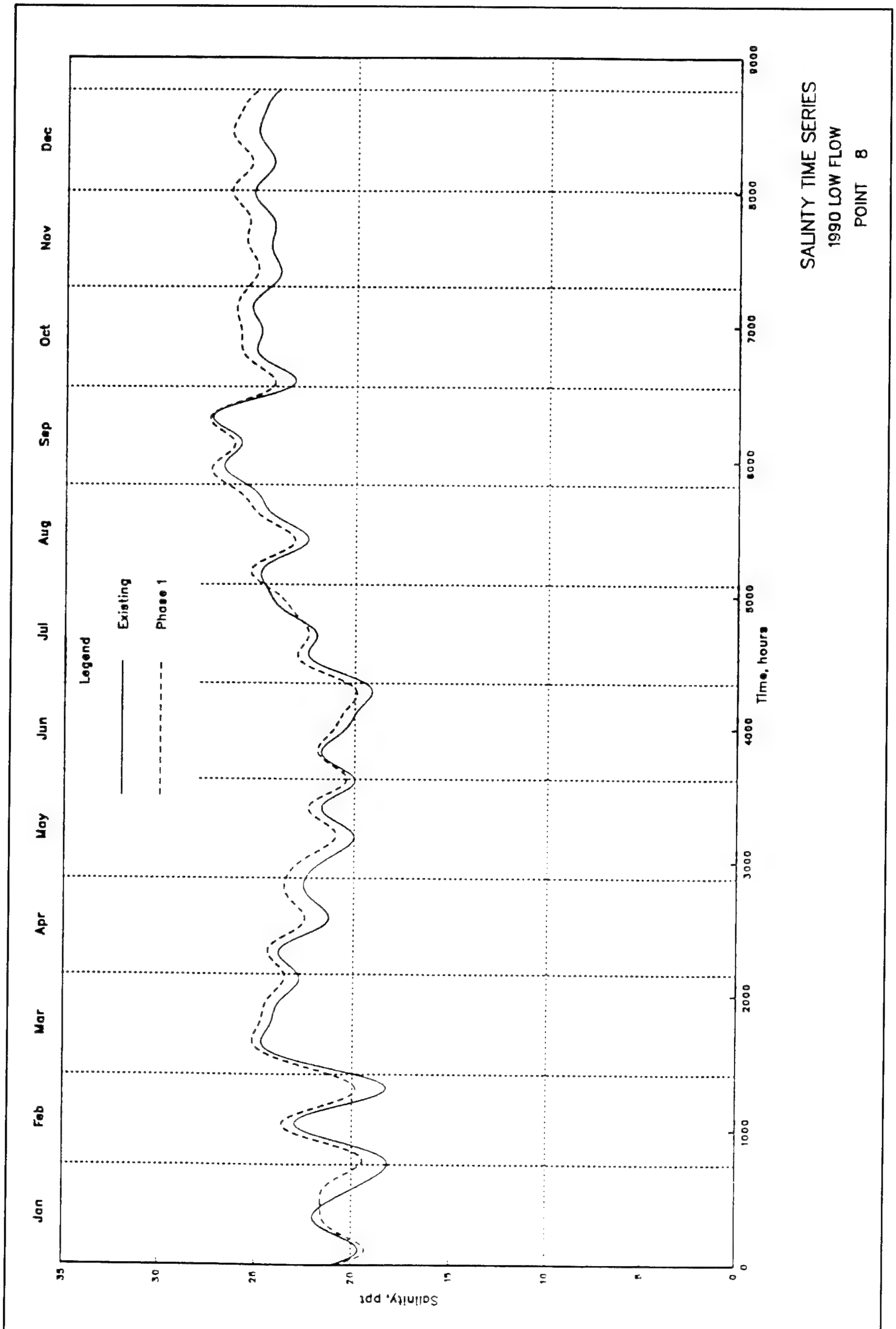
SALINTY TIME SERIES
1990 LOW FLOW
POINT 8
Legend
Existing
Phase 1
Time, hours
Salinity, ppt
Jan
Feb
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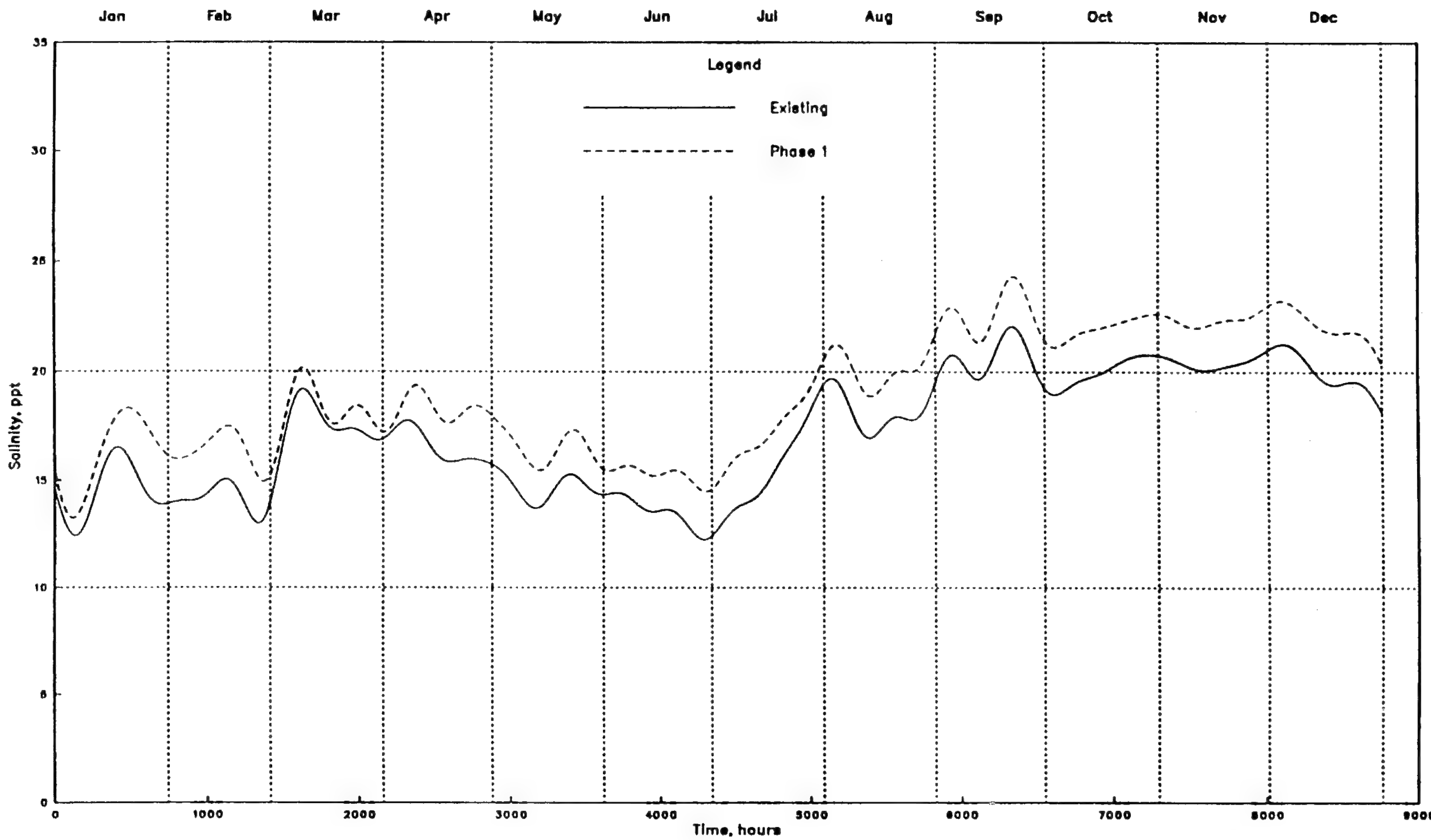
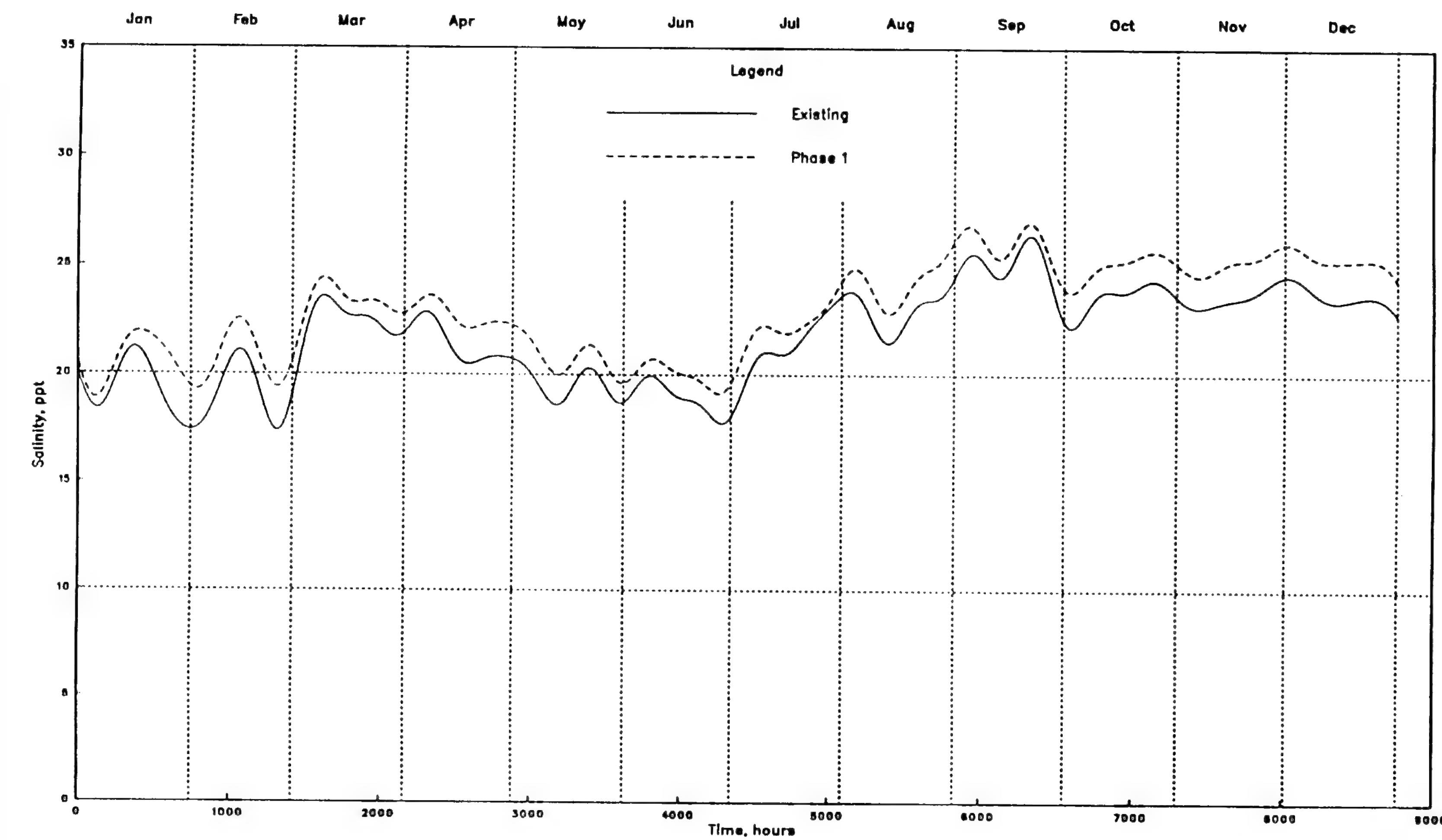
Plate 8



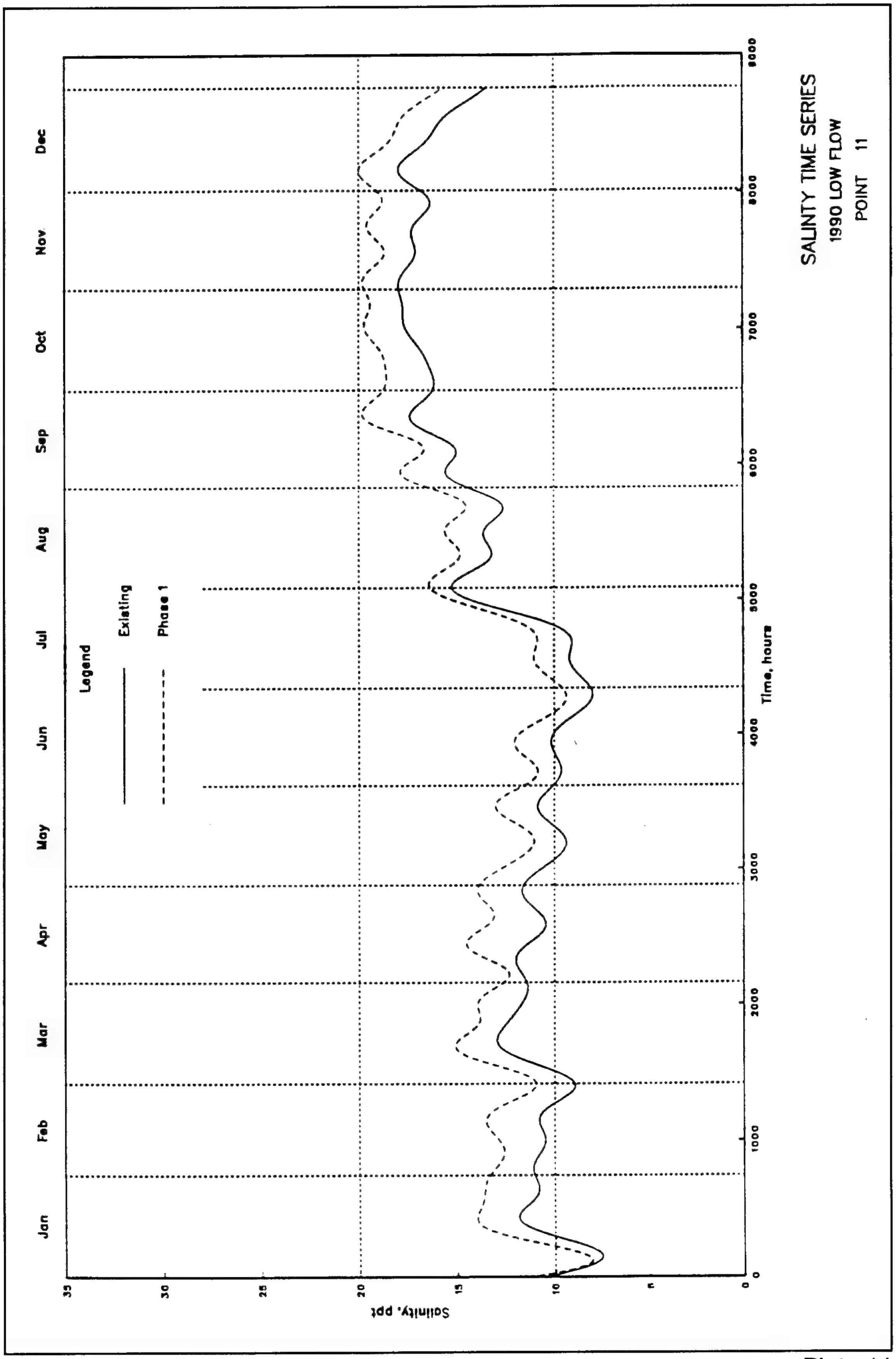
SALINTY TIME SERIES
1990 LOW FLOW
POINT 9

Plate 9



SALINTY TIME SERIES
1990 LOW FLOW
POINT 10

Plate 10


SALINTY TIME SERIES
1990 LOW FLOW
POINT 11
Legend
Existing
Phase 1
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Time, hours
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Salinity, ppt
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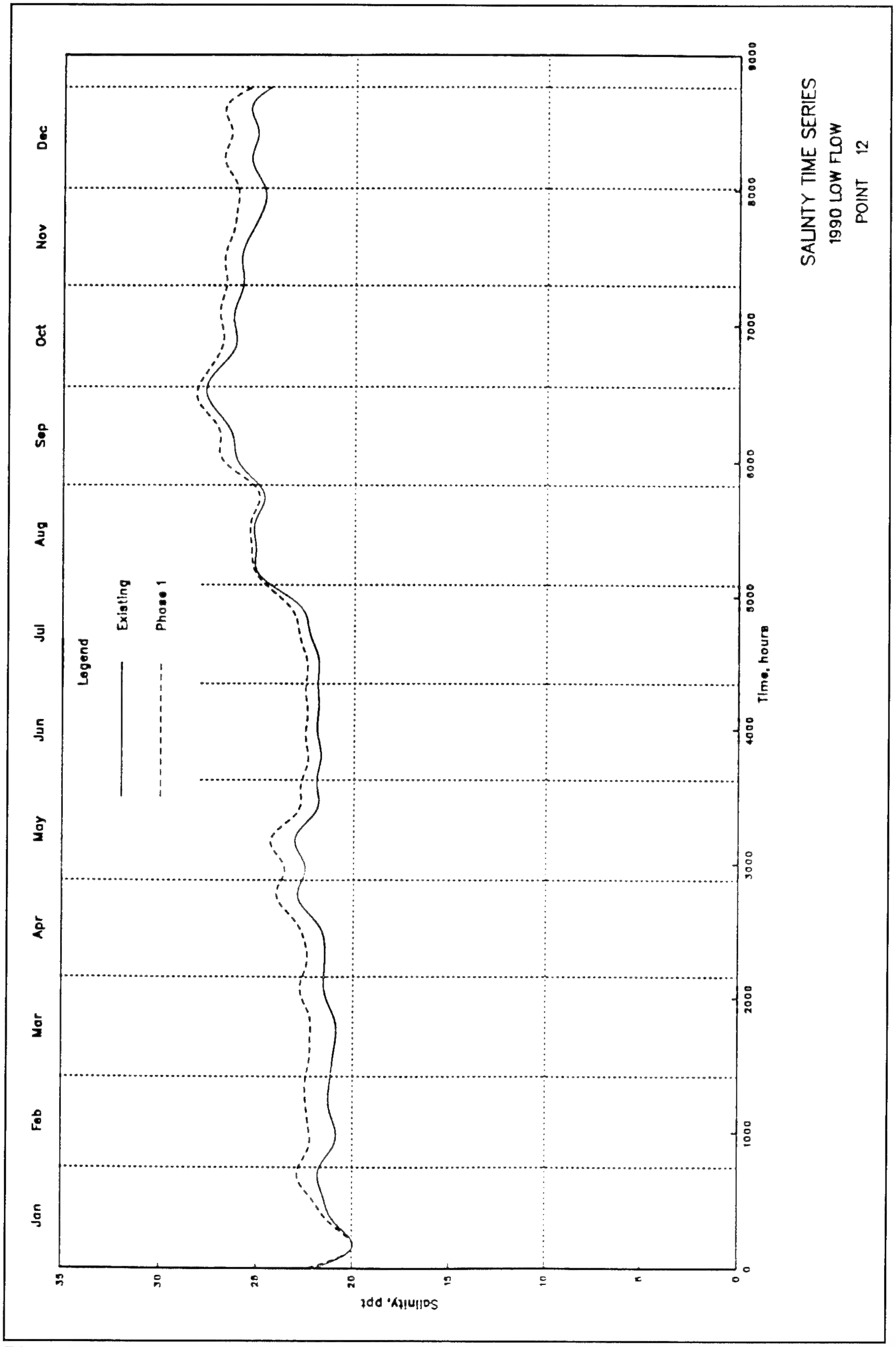
Plate 11



SALINTY TIME SERIES
1990 LOW FLOW
POINT 12
Legend
Existing
Phase 1
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Dec
Salinity, ppt
Time, hours
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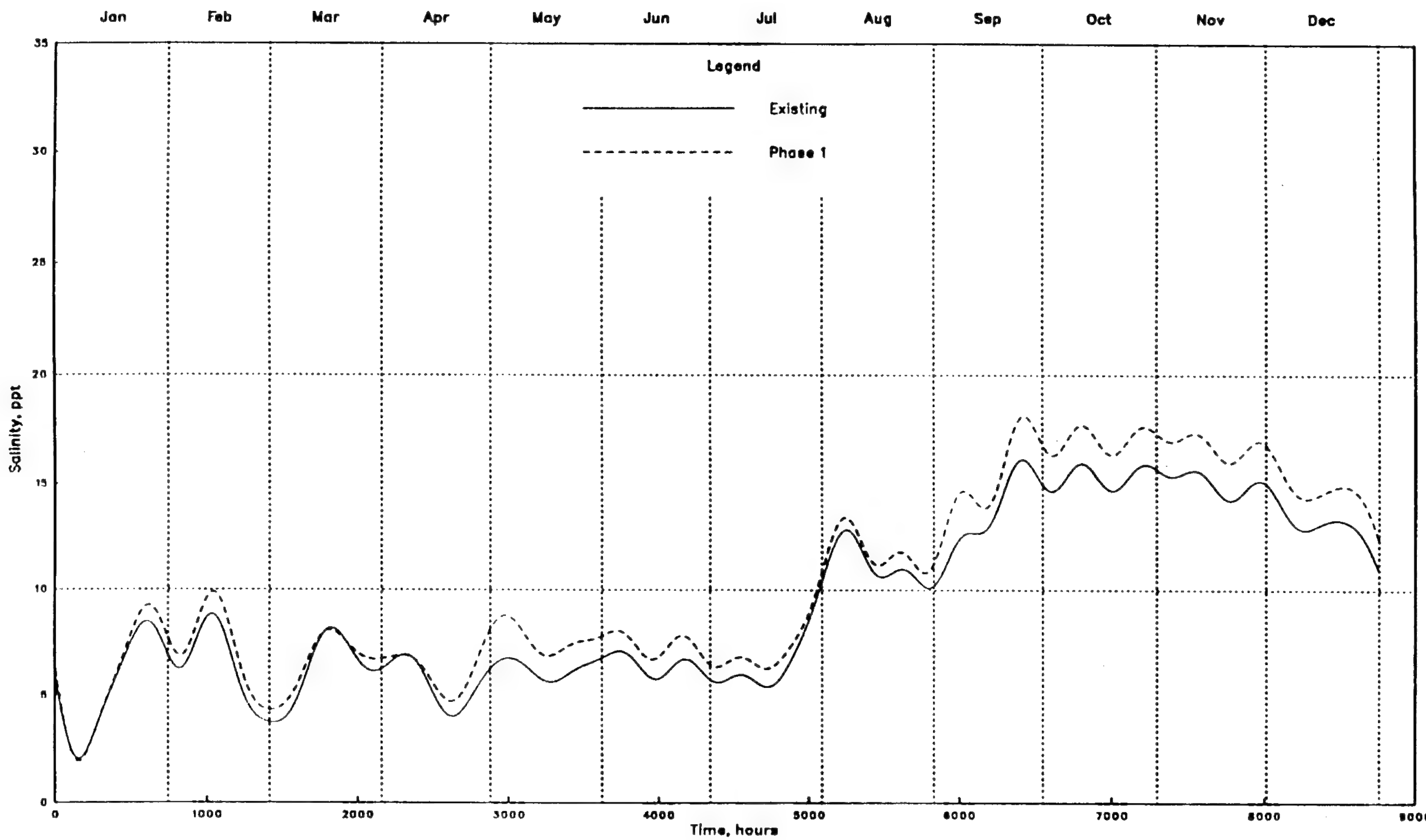
Plate 12



SALINTY TIME SERIES
1990 LOW FLOW
POINT 13

Plate 13

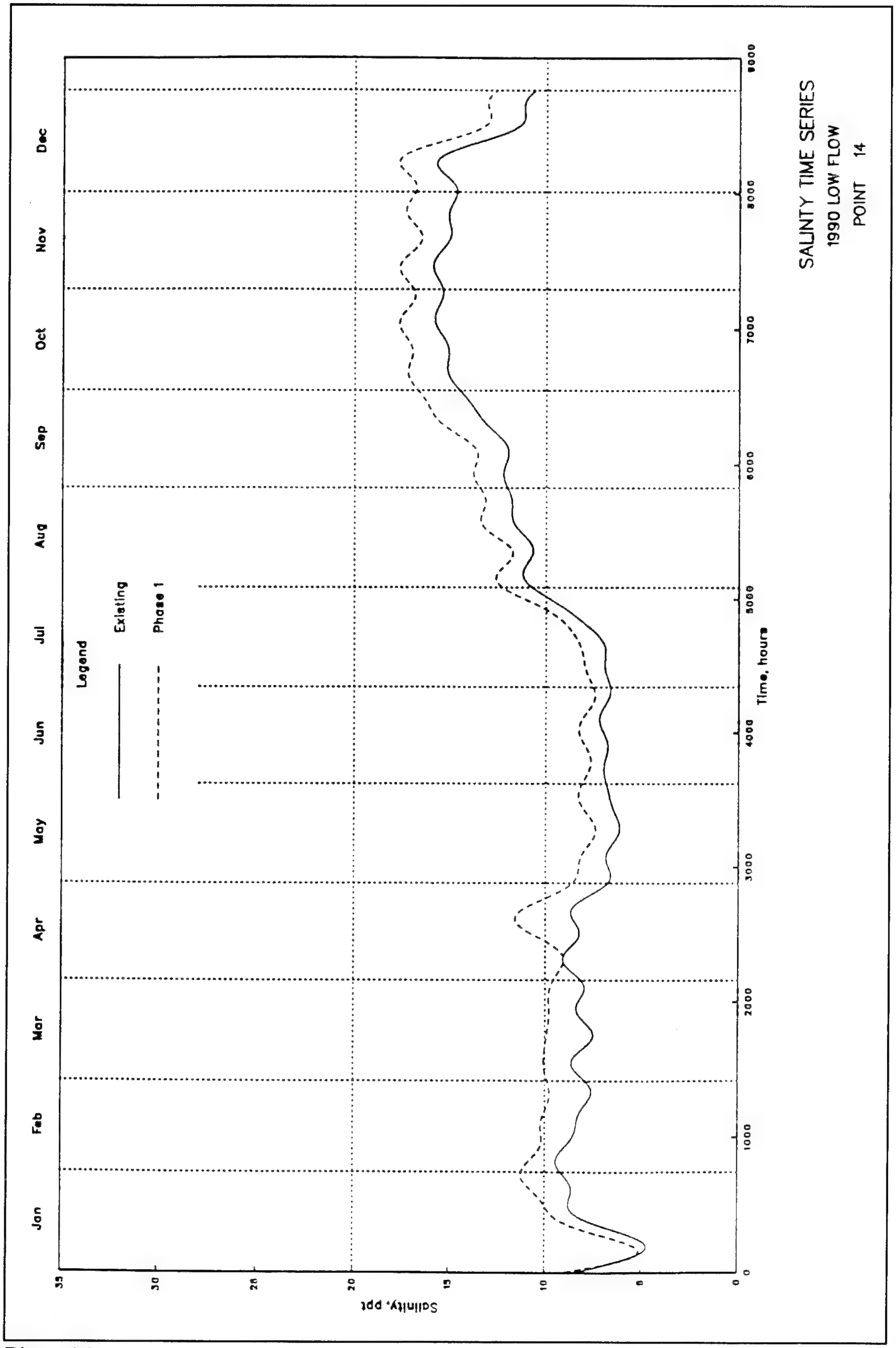

SALINTY TIME SERIES
1990 LOW FLOW
POINT 14
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
Jan
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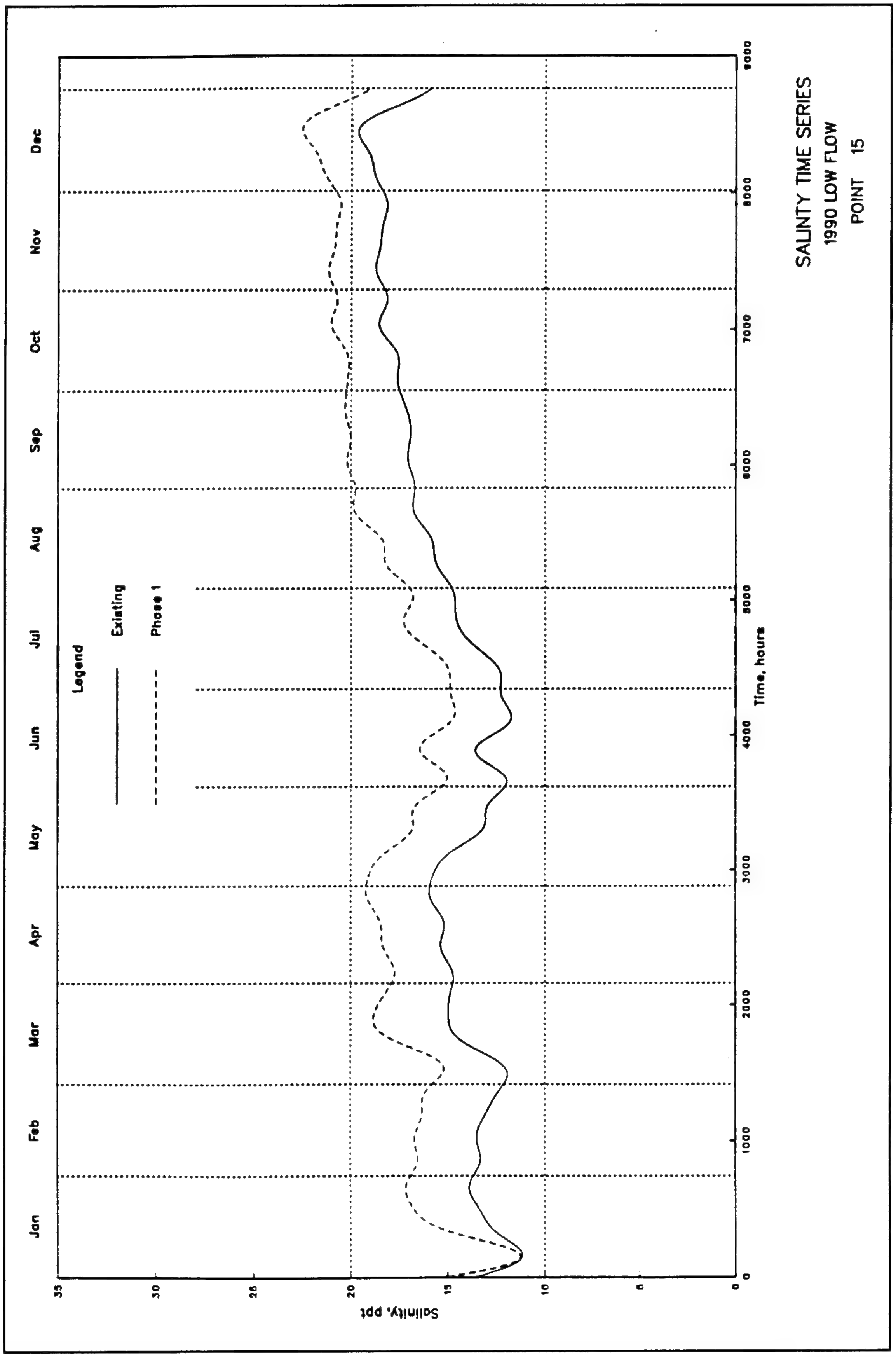
Plate 14


SALINTY TIME SERIES
1990 LOW FLOW
POINT 15
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
Jan
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May
Jun
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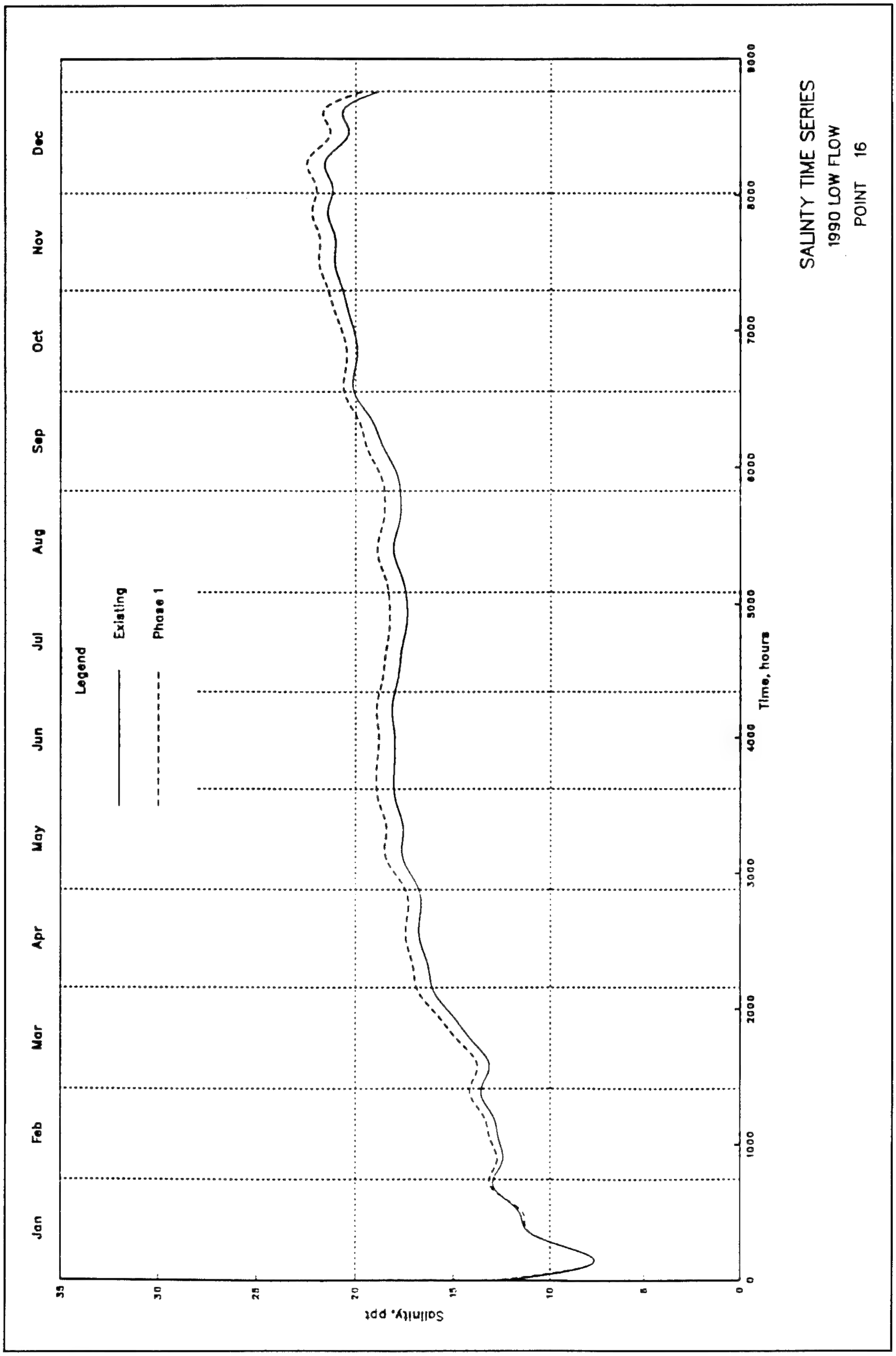

SALINTY TIME SERIES
1990 LOW FLOW
POINT 16
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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Aug
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Oct
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Dec
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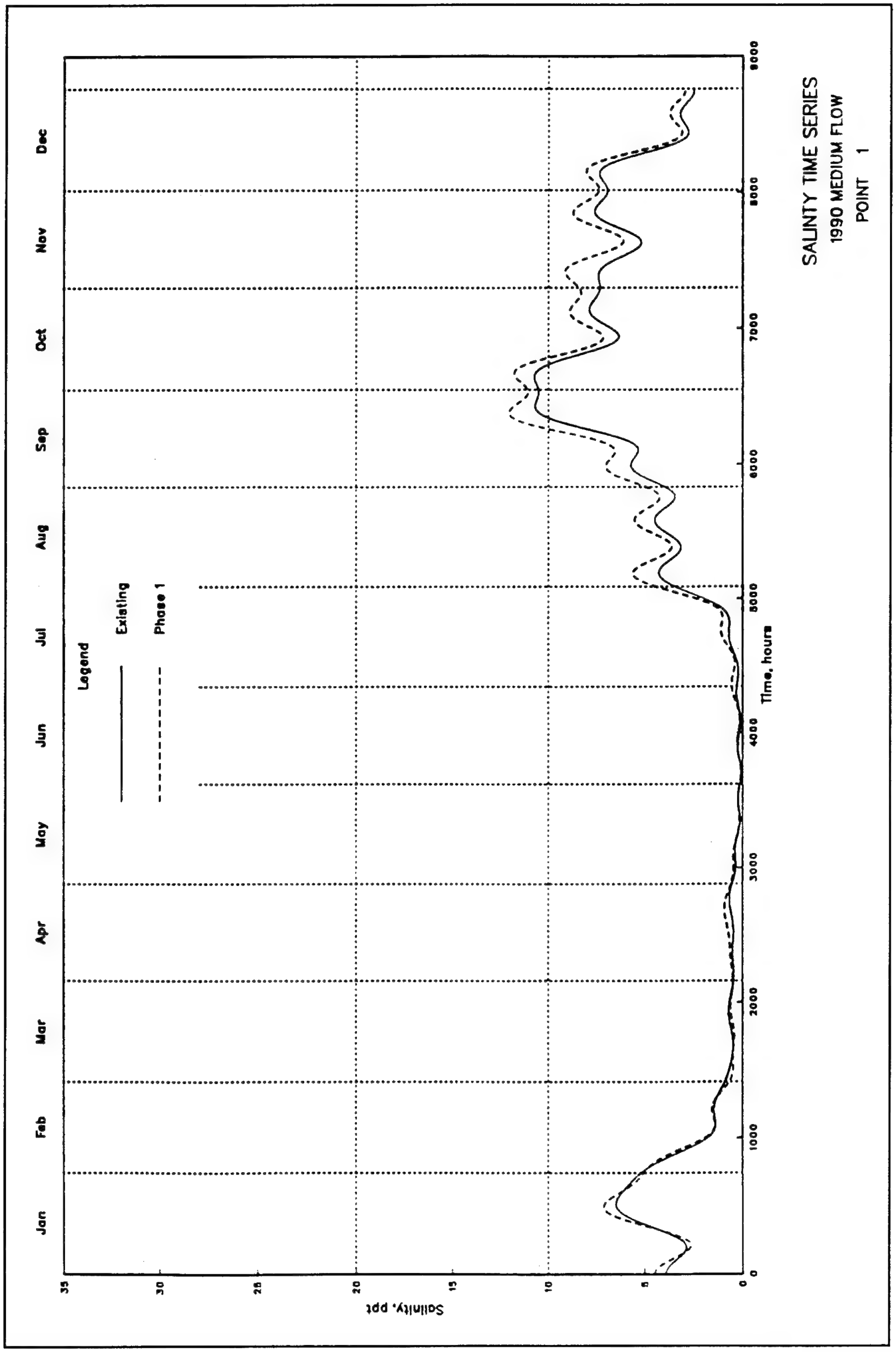
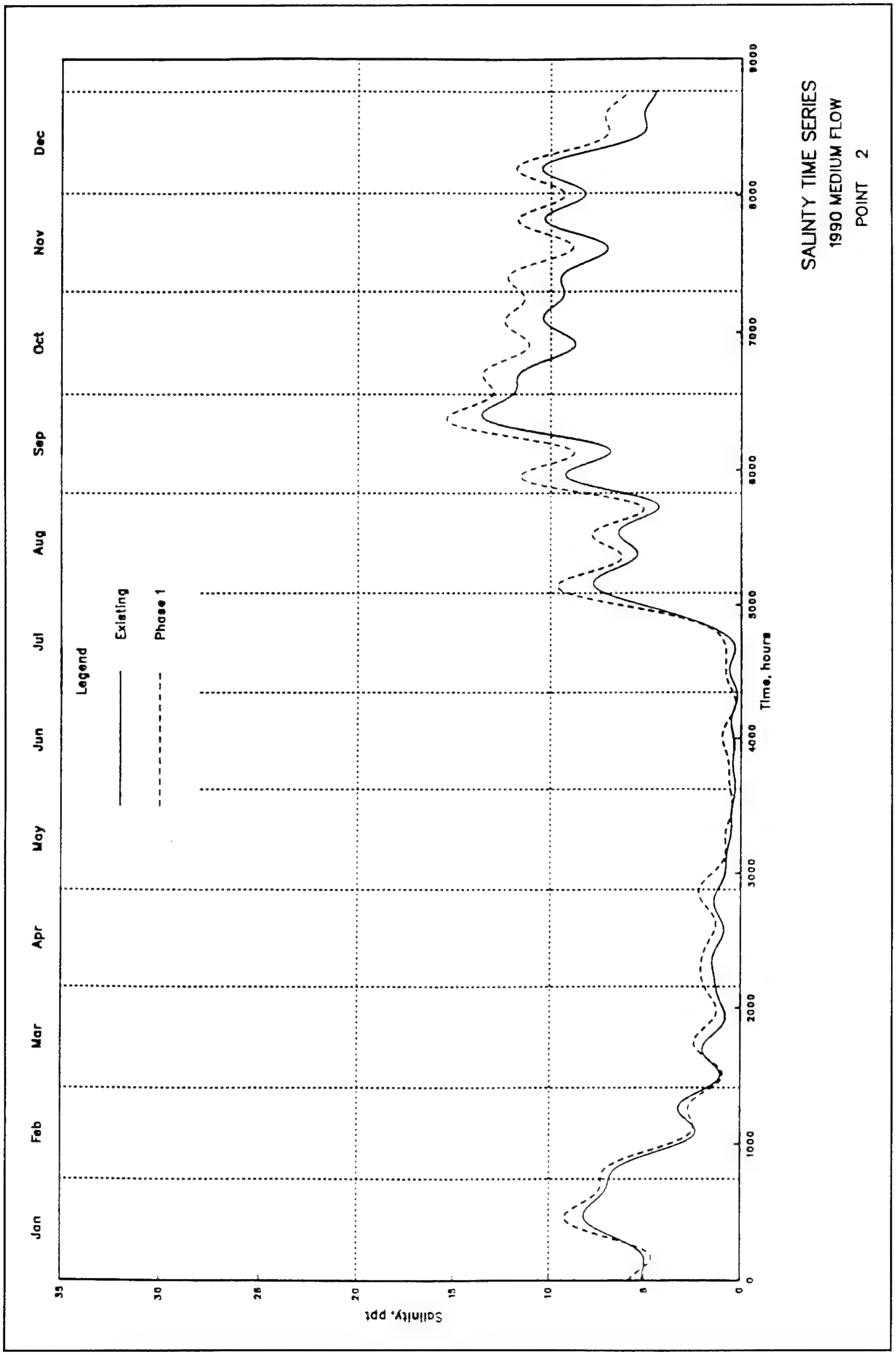
Plate 16



SALINTY TIME SERIES
1990 MEDIUM FLOW
POINT 1

Plate 17


SALINTY TIME SERIES
1990 MEDIUM FLOW
POINT 2
Legend
Existing
Phase 1
Jan
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May
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Jul
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Dec
Time, hours
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Salinity, ppt
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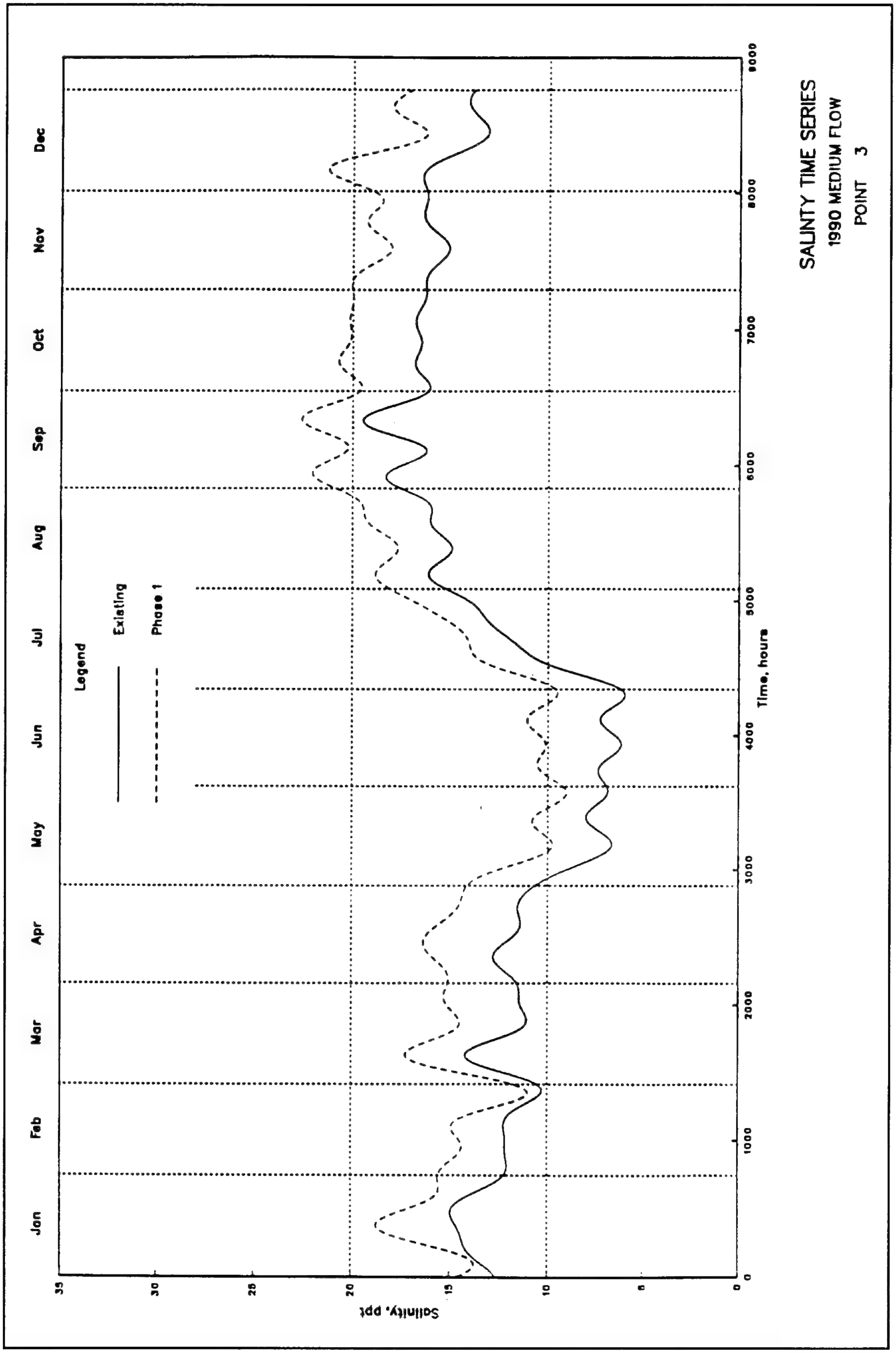
Plate 18


SALINTY TIME SERIES
1990 MEDIUM FLOW
POINT 3
Salinity, ppt
Time, hours
Legend
Existing
Phase 1
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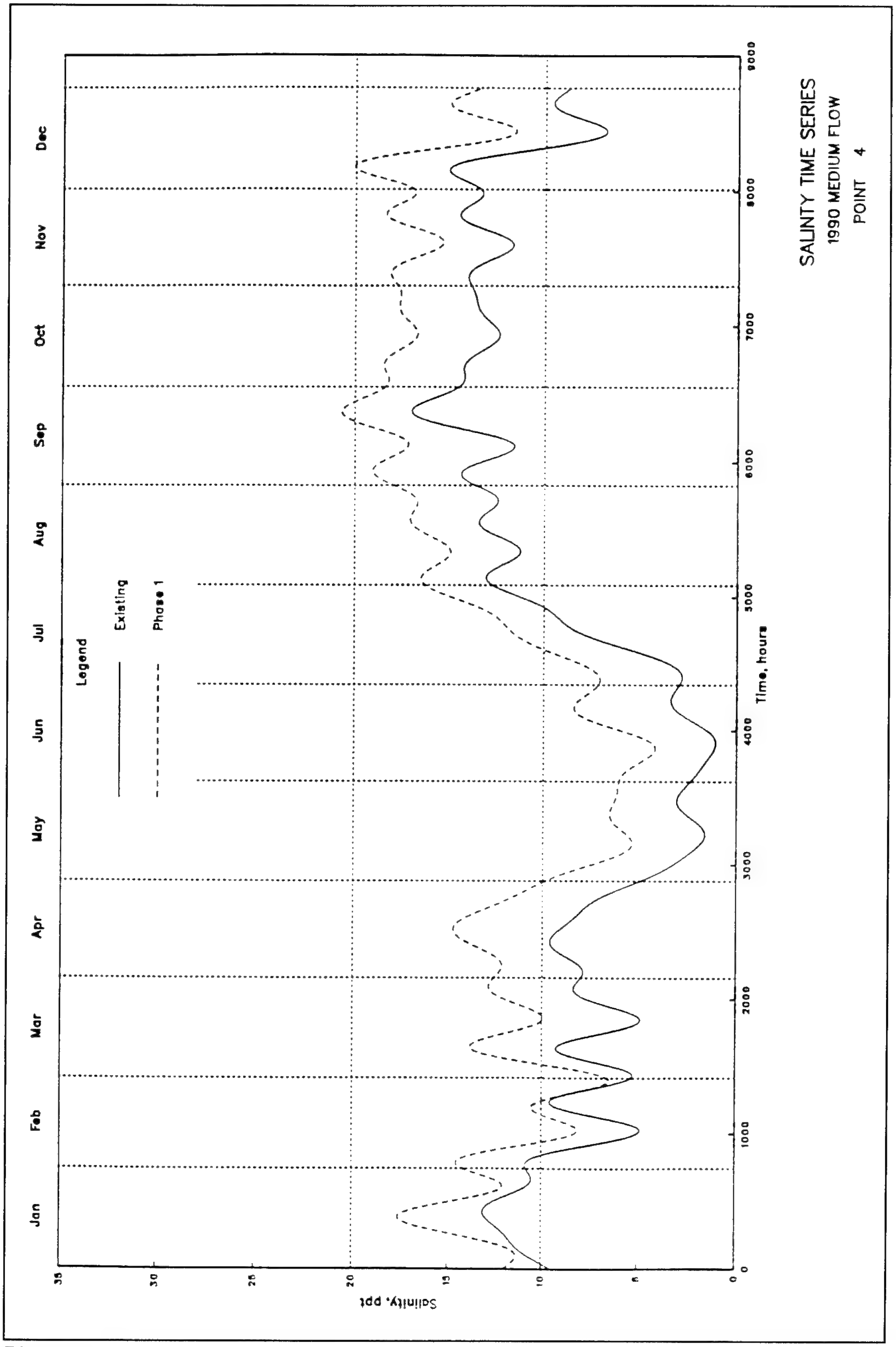

SALINTY TIME SERIES
1990 MEDIUM FLOW
POINT 4
Legend
Existing
Phase 1
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Salinity, ppt
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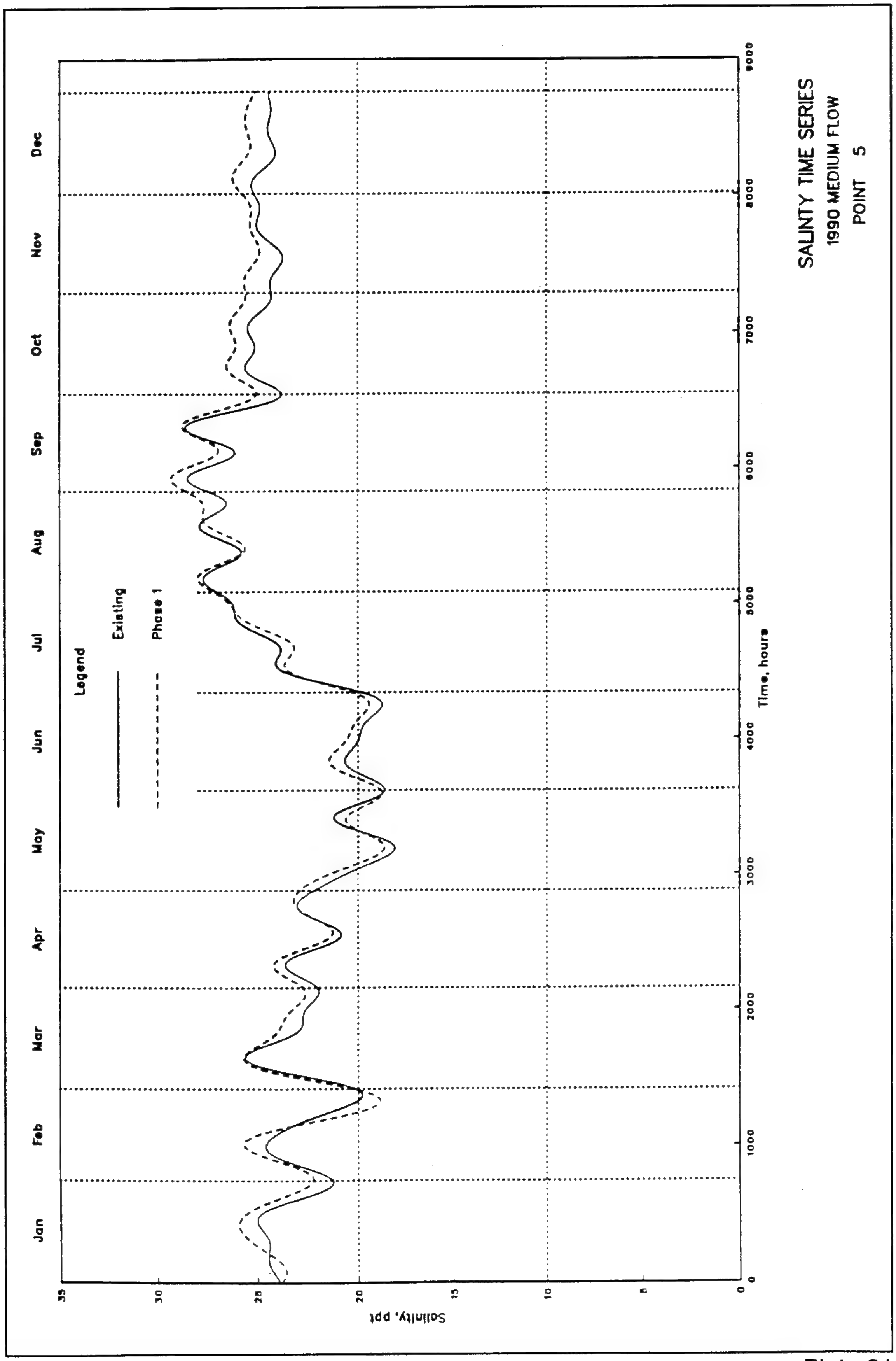
Plate 20



SALINTY TIME SERIES
1990 MEDIUM FLOW
POINT 5
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Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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Plate 21

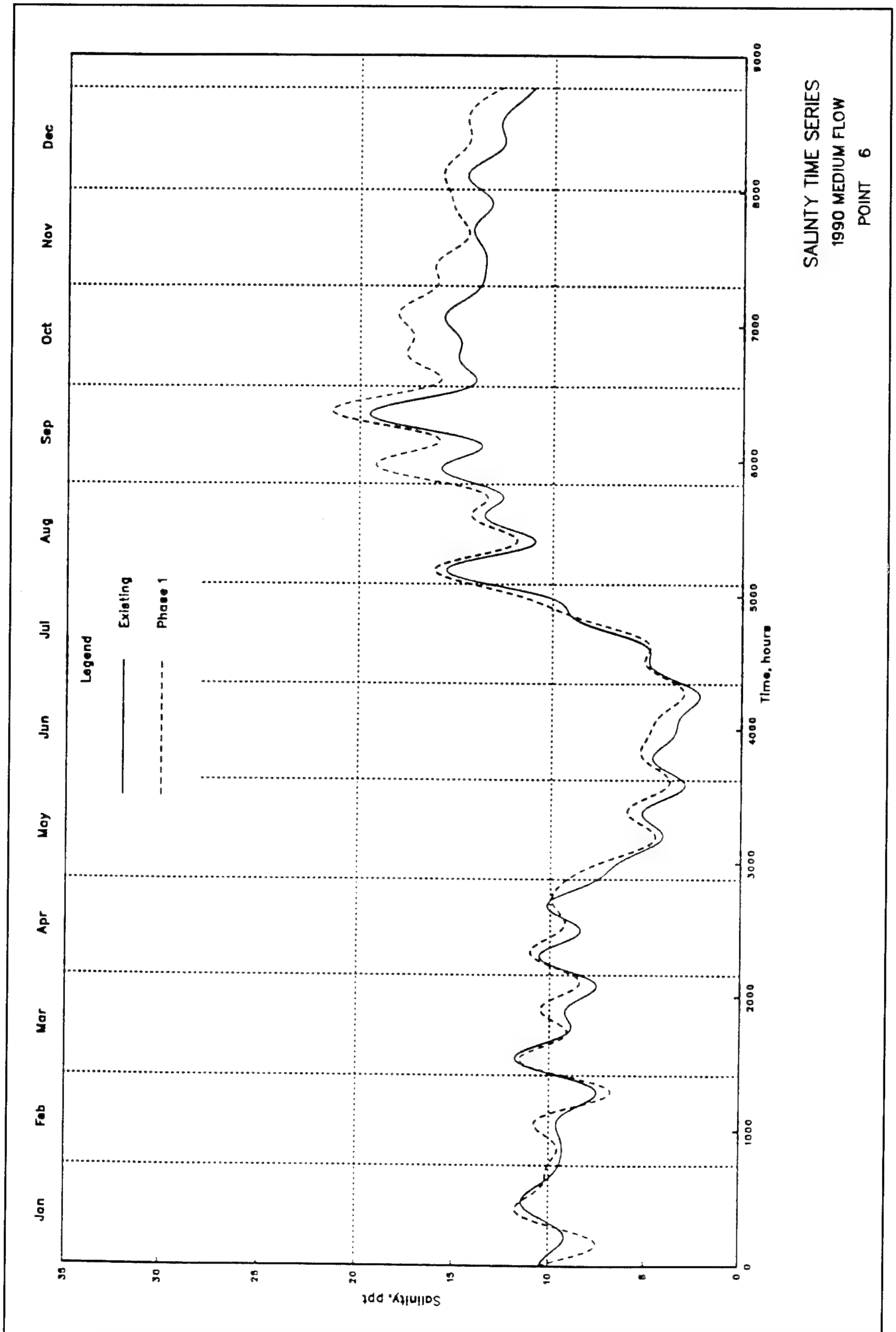
SALINTY TIME SERIES
1990 MEDIUM FLOW
POINT 6
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
Jan
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Plate 22

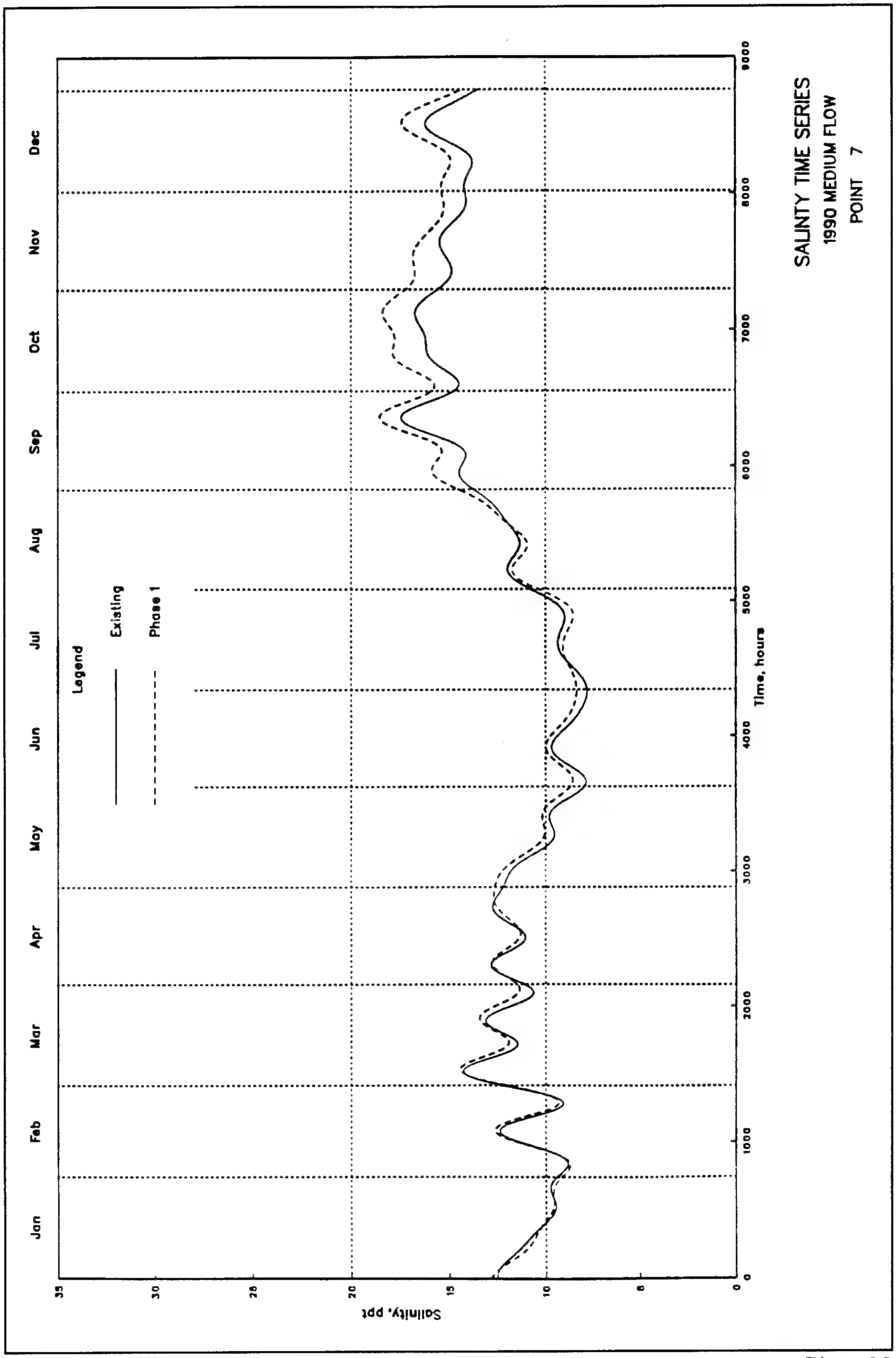
SALINTY TIME SERIES
1990 MEDIUM FLOW
POINT 7
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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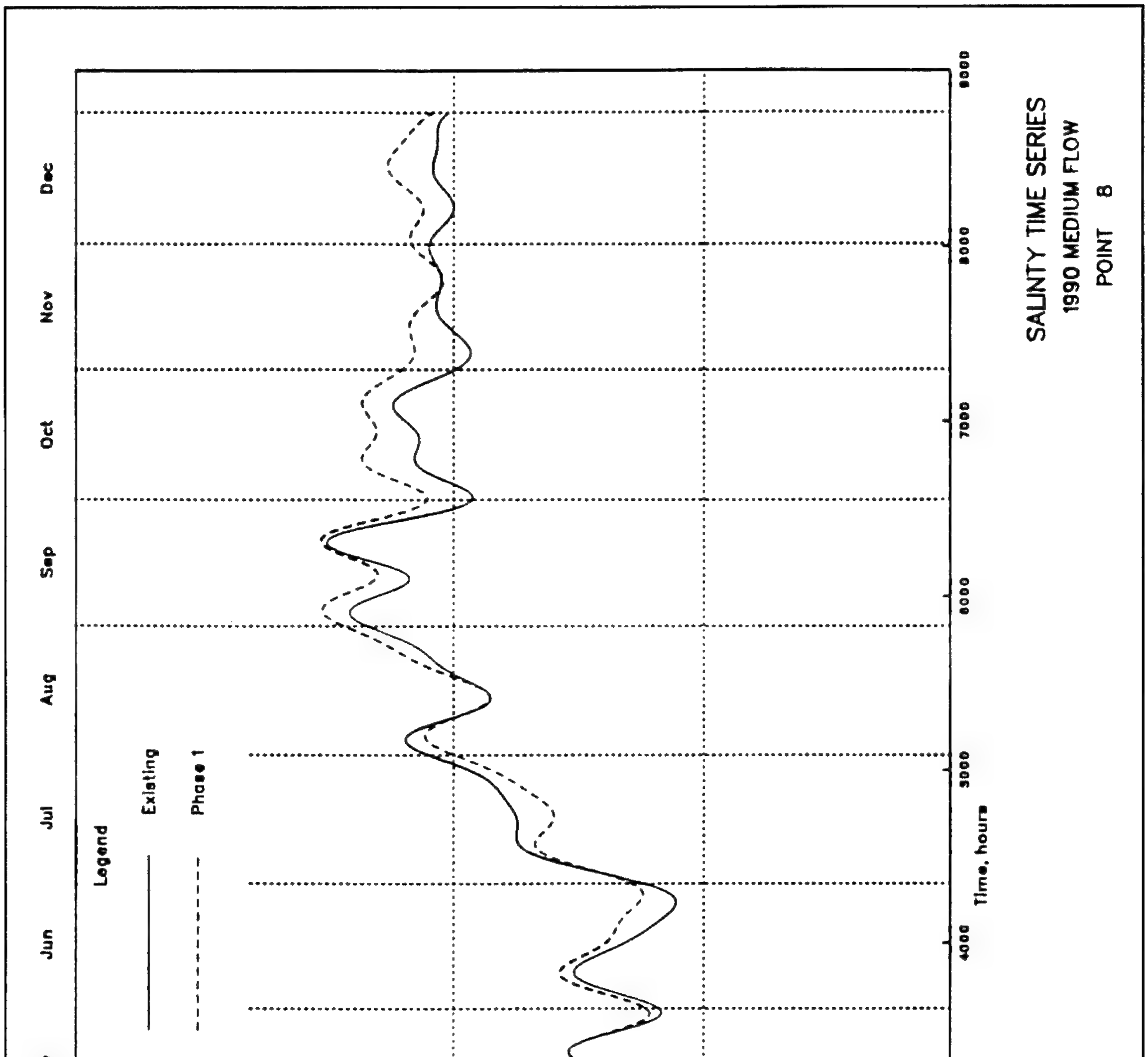
Plate 23



SALINTY TIME SERIES
1990 MEDIUM FLOW
POINT 8
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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Plate 24

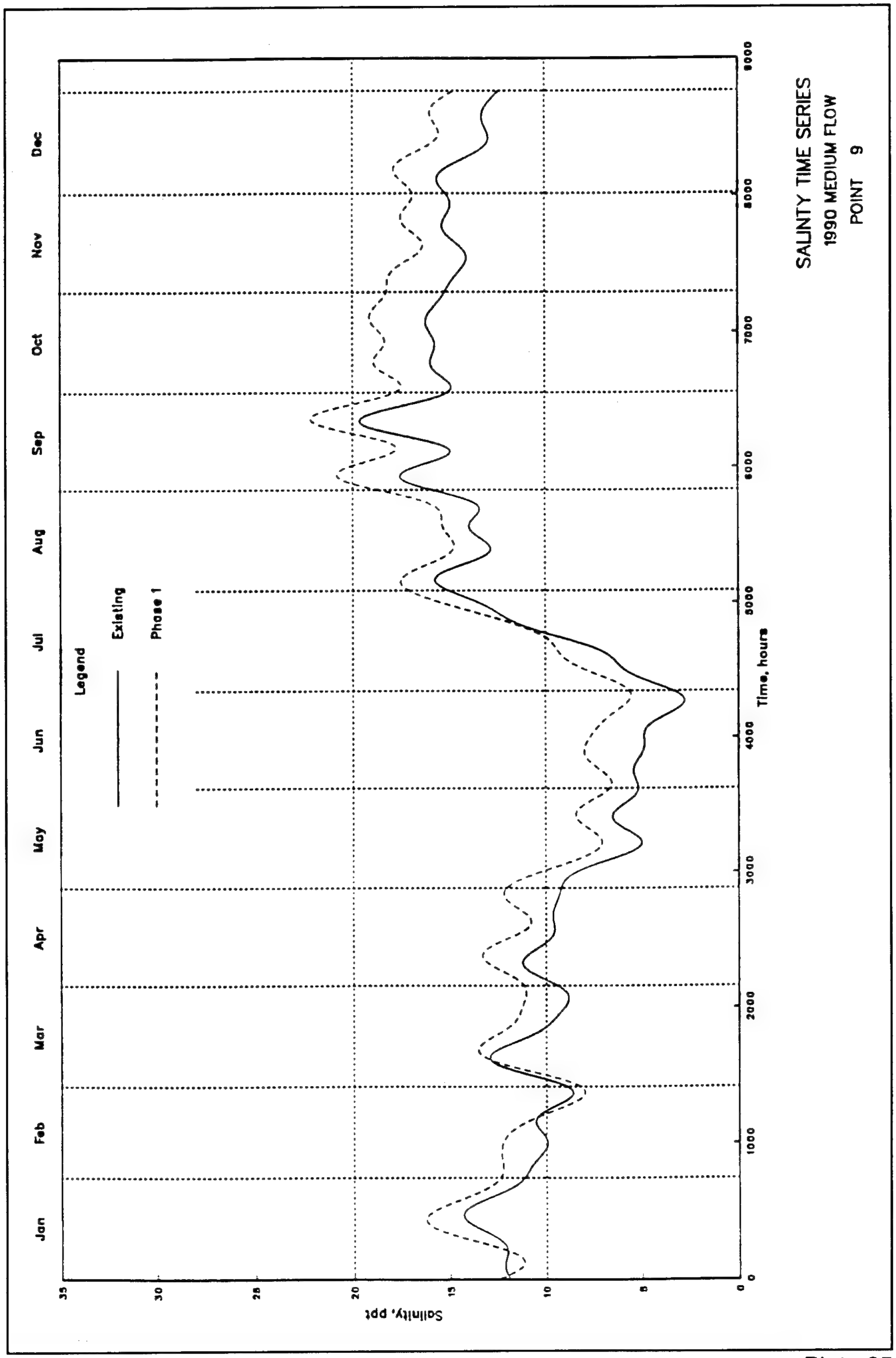
SALINTY TIME SERIES
1990 MEDIUM FLOW
POINT 9
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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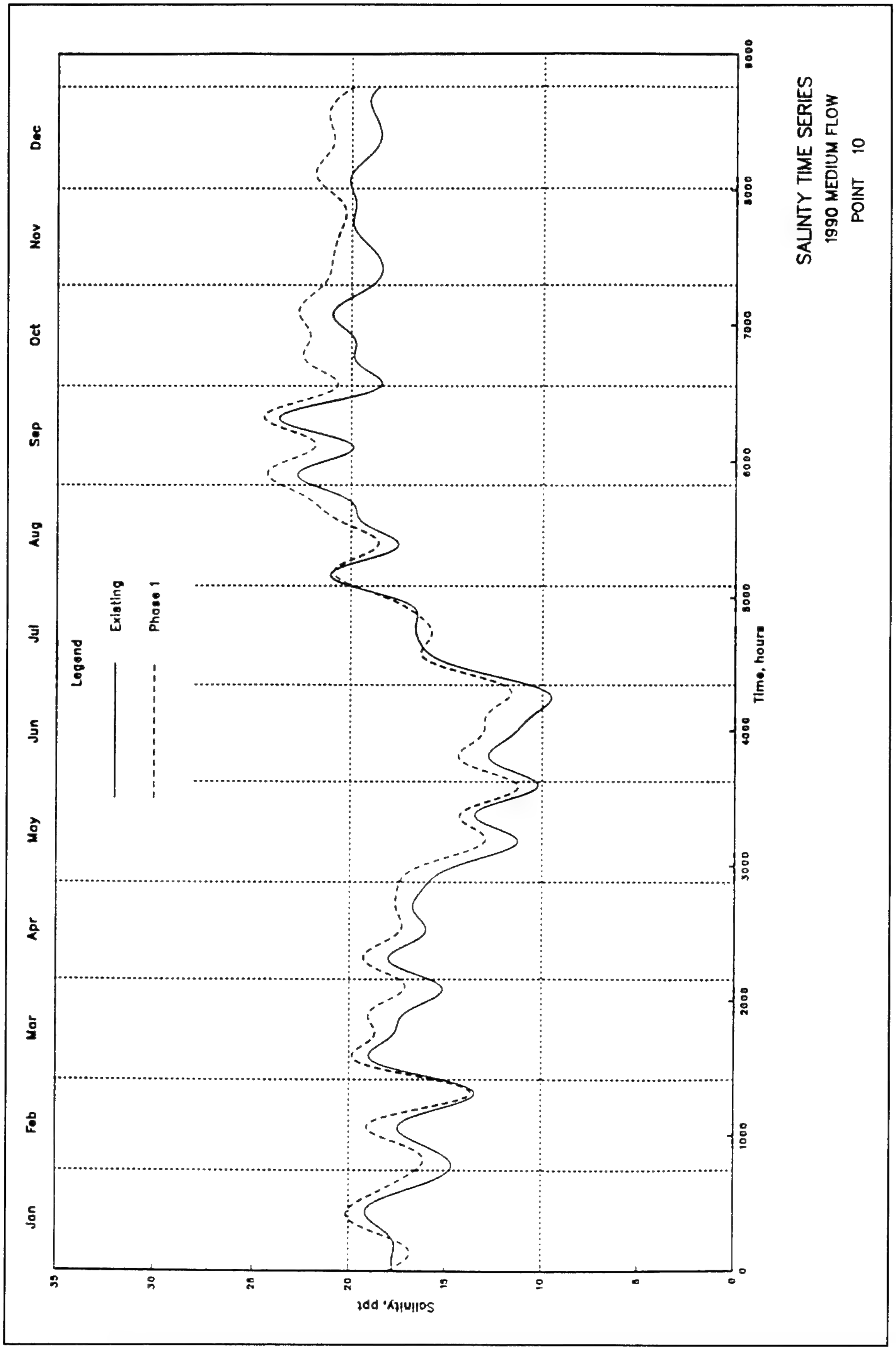
Plate 25



SALINTY TIME SERIES
1990 MEDIUM FLOW
POINT 10
Legend
Existing
Phase 1
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Time, hours
Salinity, ppt
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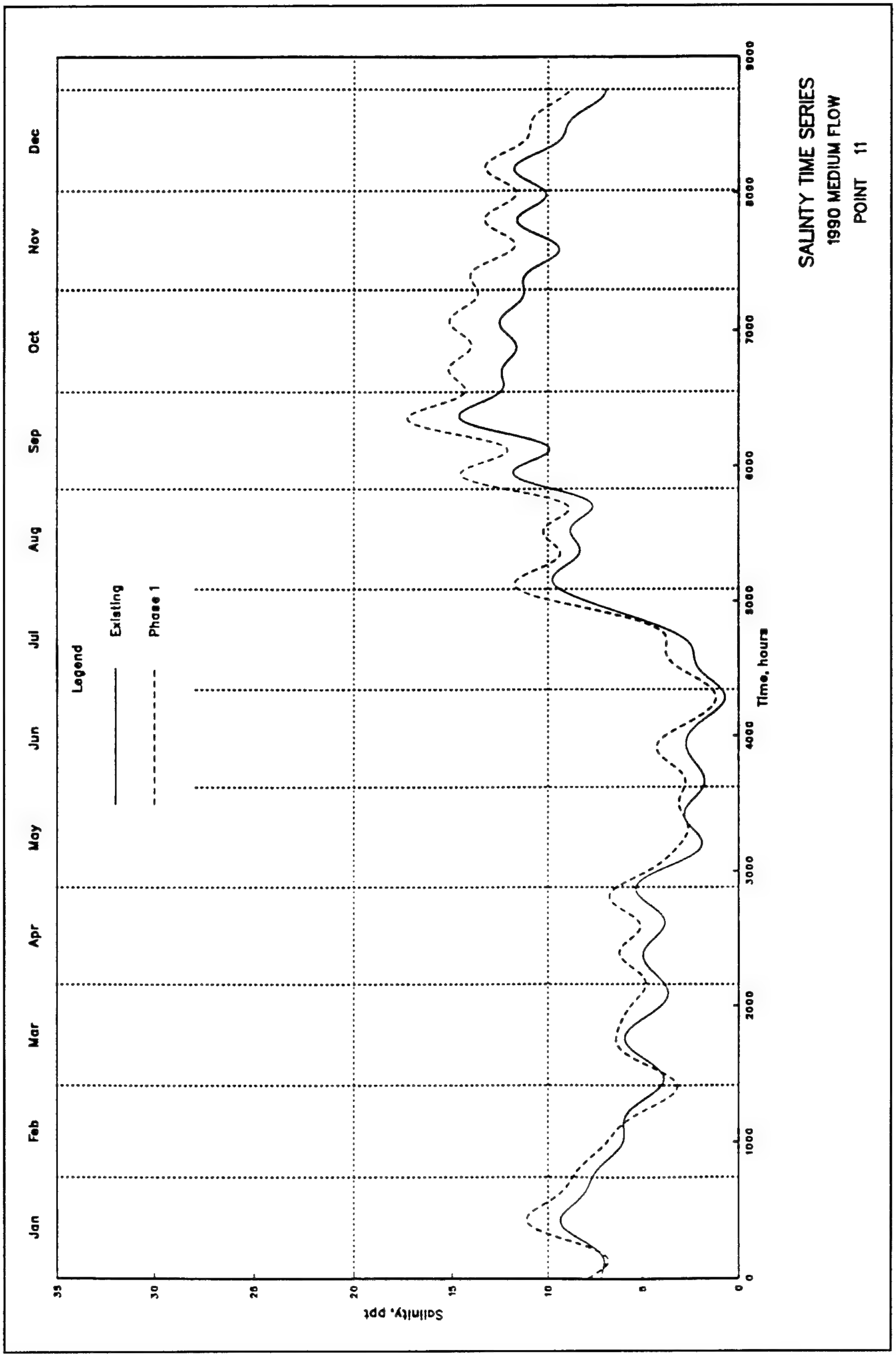
Plate 26



SALINTY TIME SERIES
1990 MEDIUM FLOW
POINT 11
Legend
Existing
Phase 1
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Salinity, ppt
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Plate 27

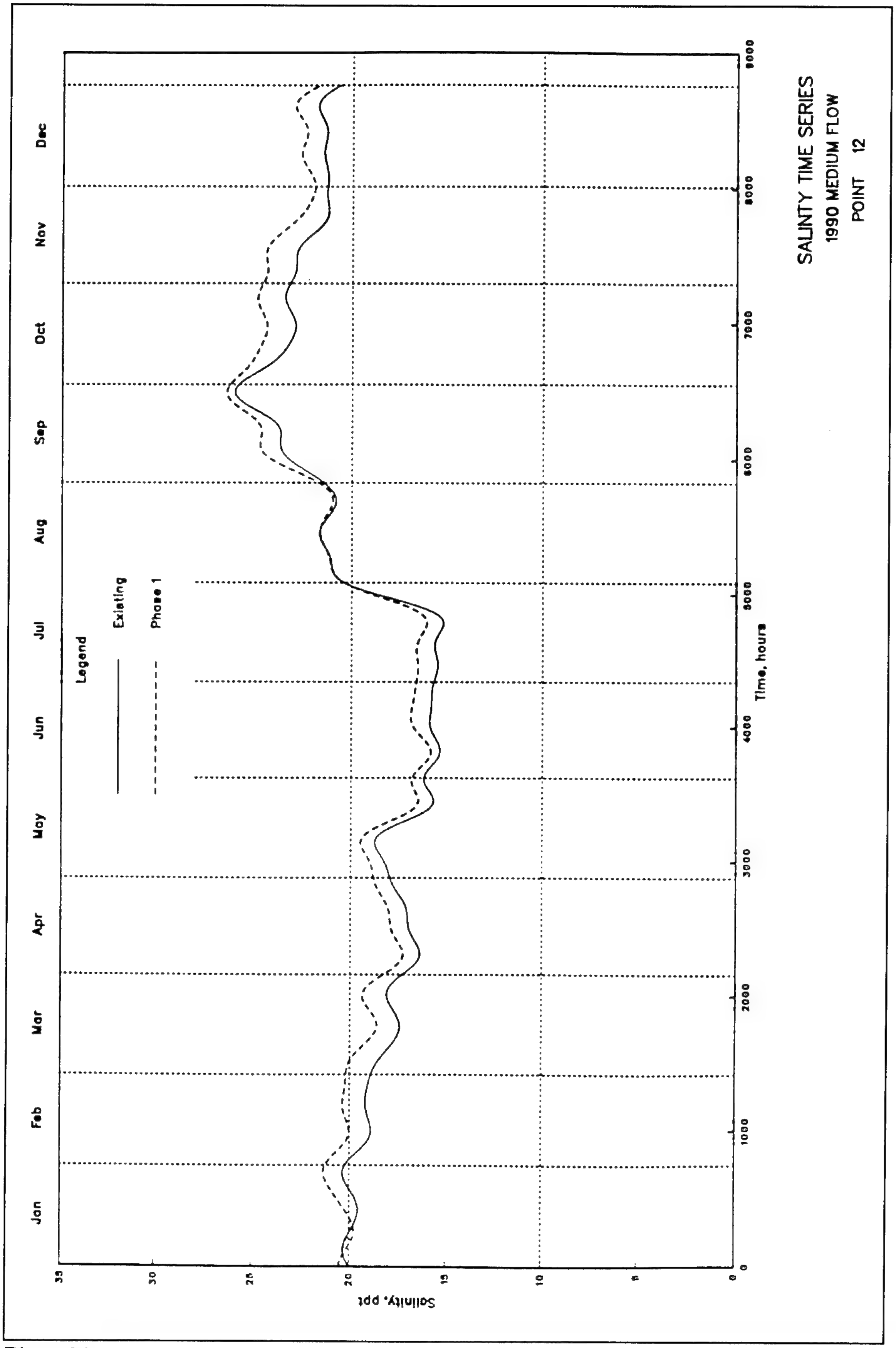
SALINTY TIME SERIES
1990 MEDIUM FLOW
POINT 12
Legend
Existing
Phase 1
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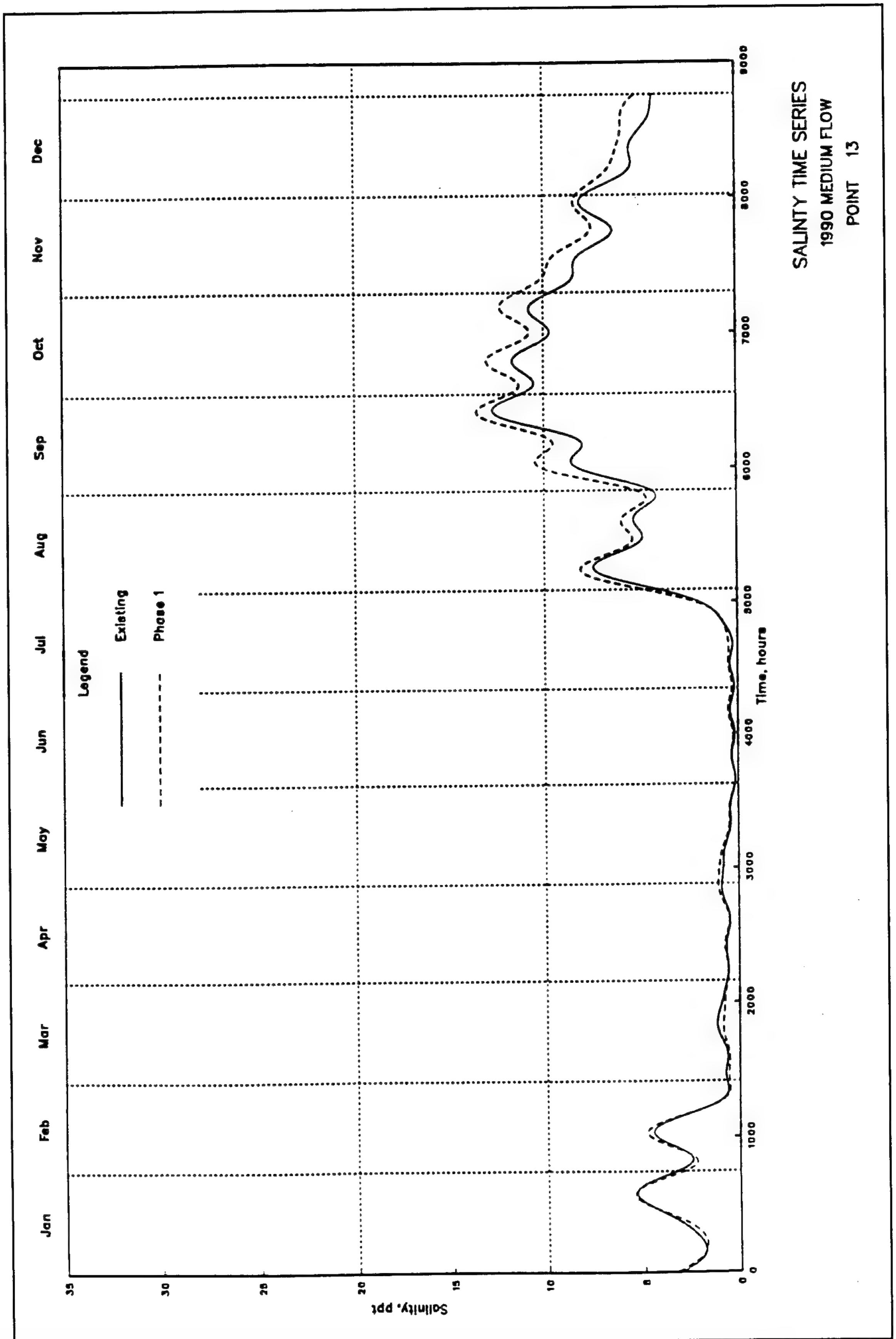
Plate 28



SALINTY TIME SERIES
1990 MEDIUM FLOW
POINT 13
Legend
Existing
Phase 1
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Salinity, ppt
Time, hours
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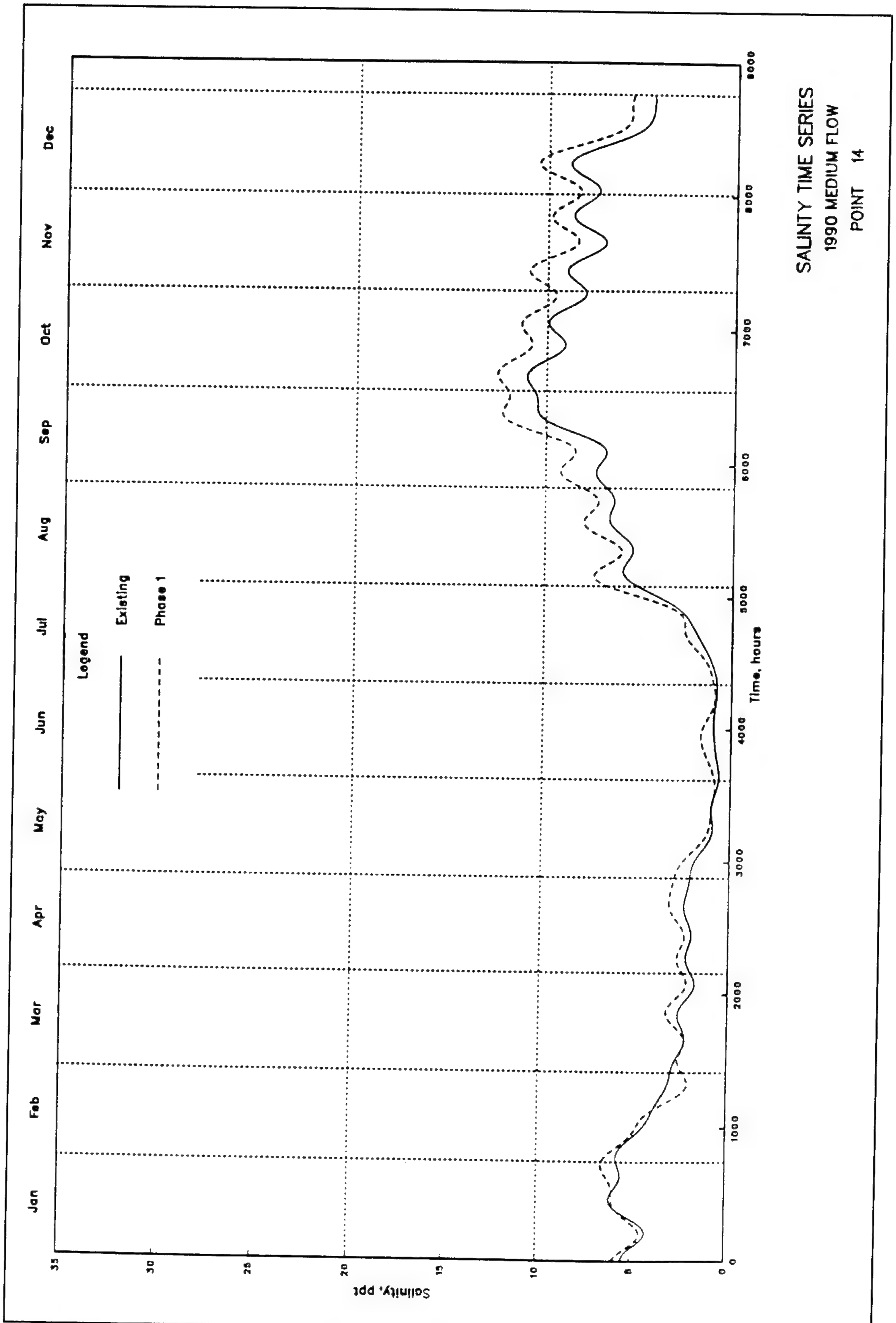
Plate 29


SALINITY TIME SERIES
1990 MEDIUM FLOW
POINT 14
Legend
Existing
Phase 1
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Salinity, ppt
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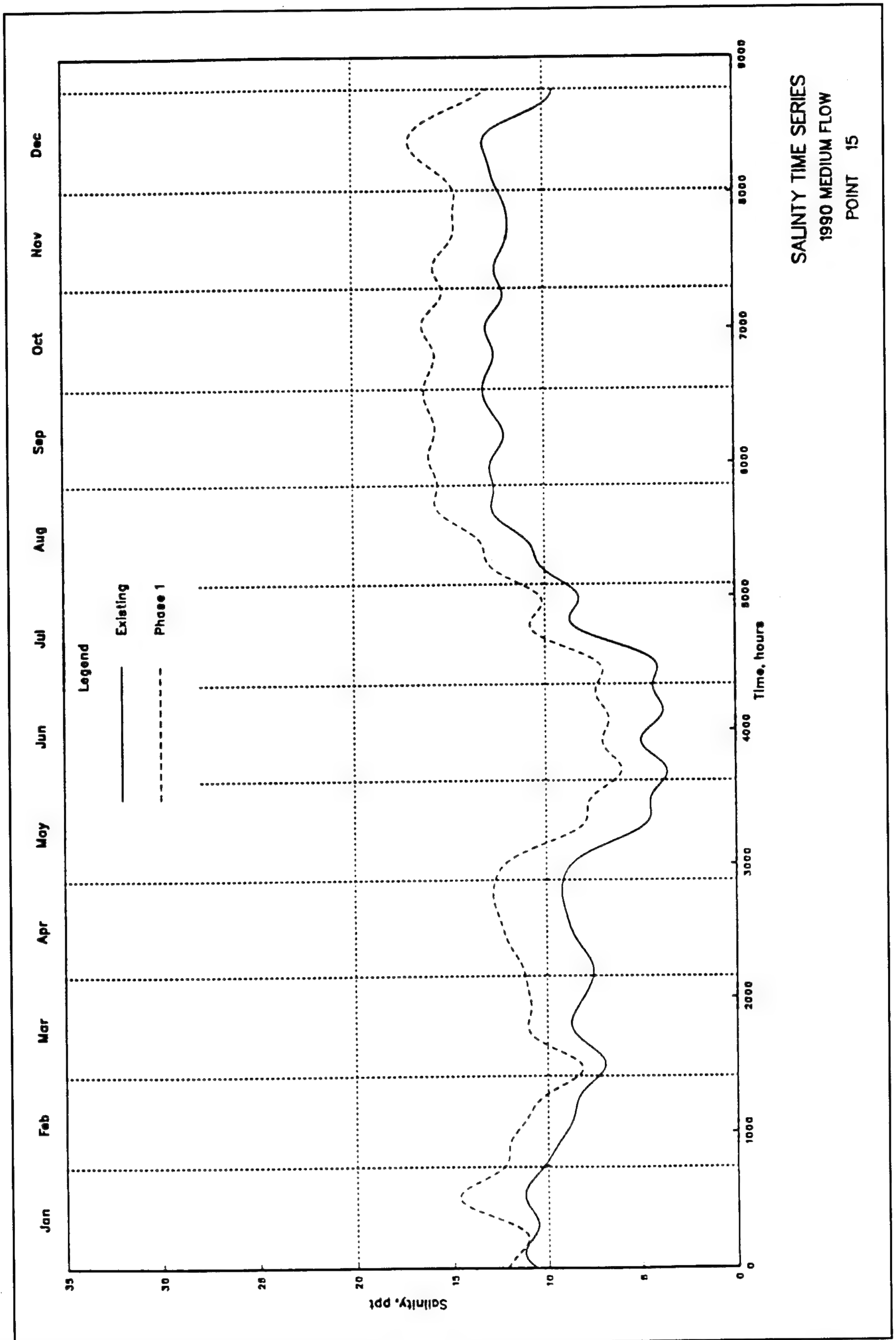
Plate 30


SALINTY TIME SERIES
1990 MEDIUM FLOW
POINT 15
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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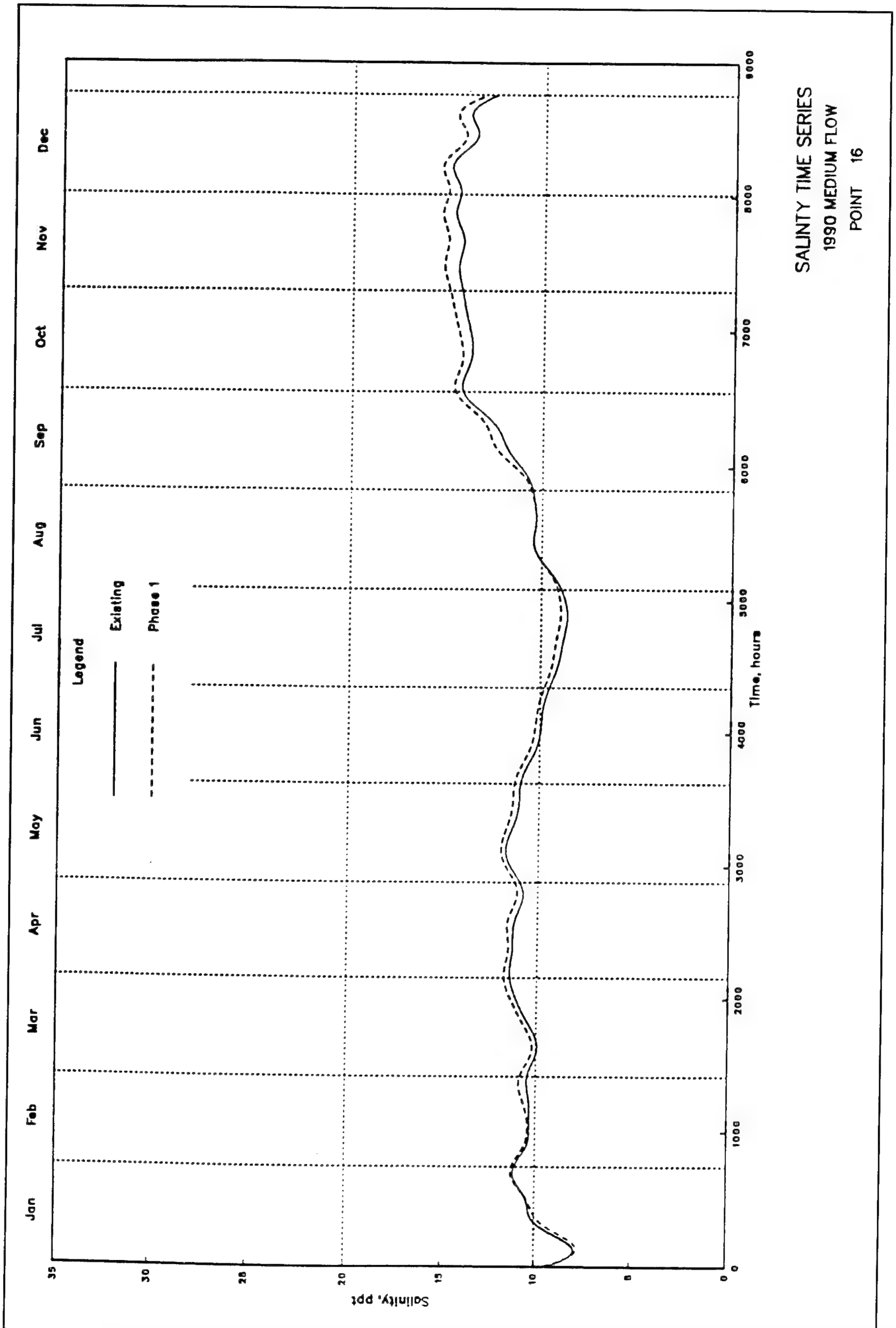
SALINTY TIME SERIES
1990 MEDIUM FLOW
POINT 16
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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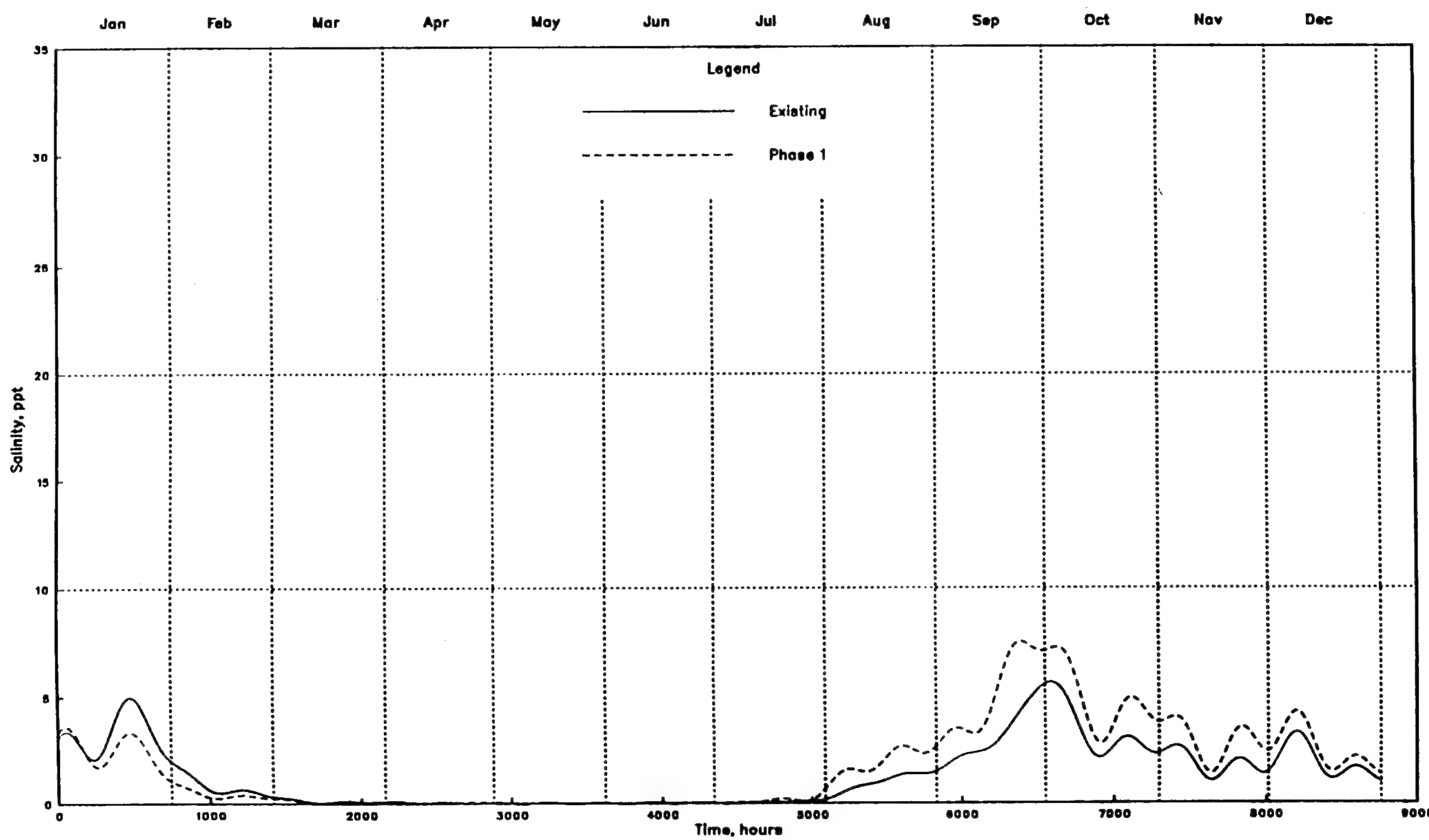
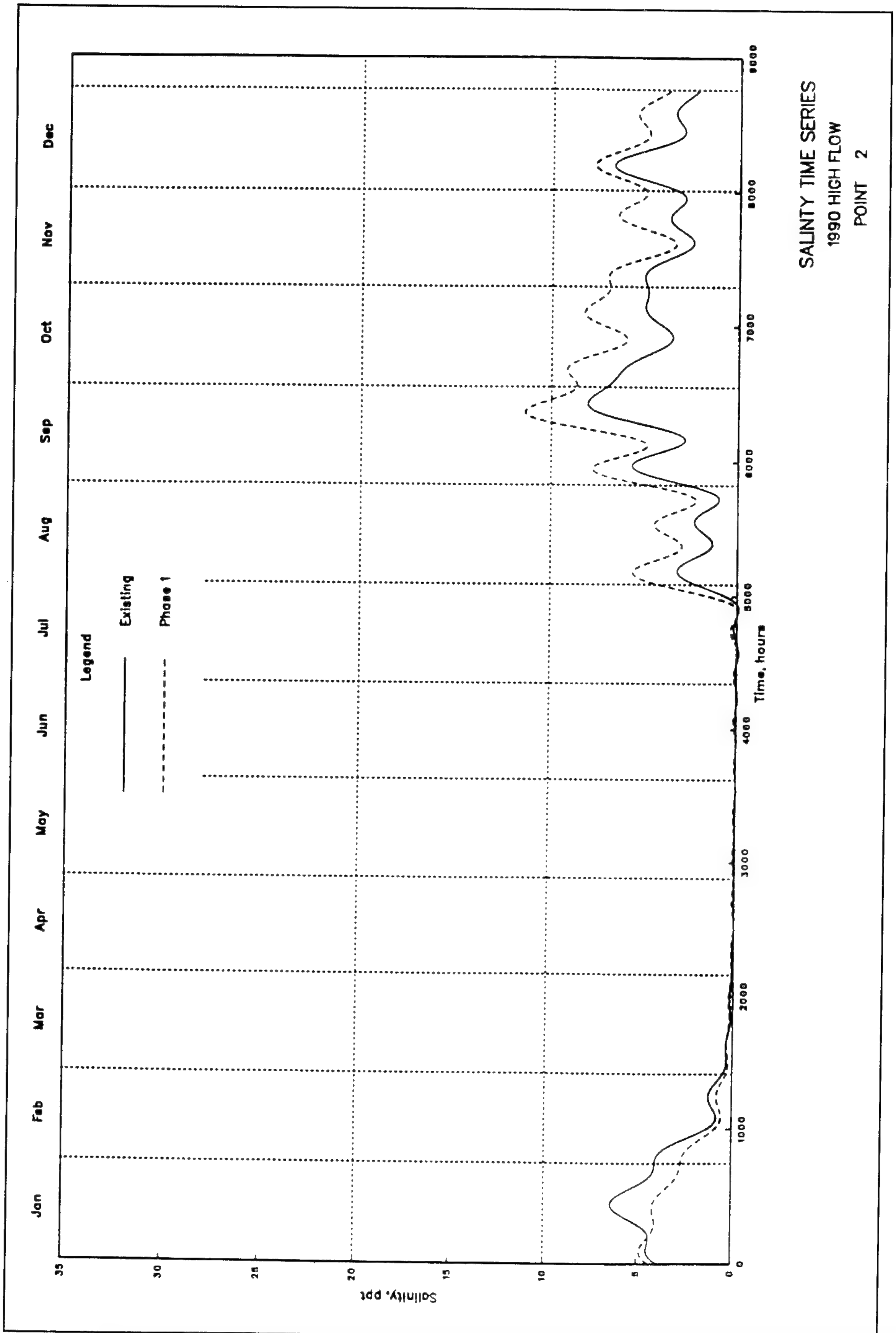
Plate 32



SALINTY TIME SERIES
1990 HIGH FLOW
POINT 1


SALINTY TIME SERIES
1990 HIGH FLOW
POINT 2
Legend
Existing
Phase 1
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Salinity, ppt
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Time, hours
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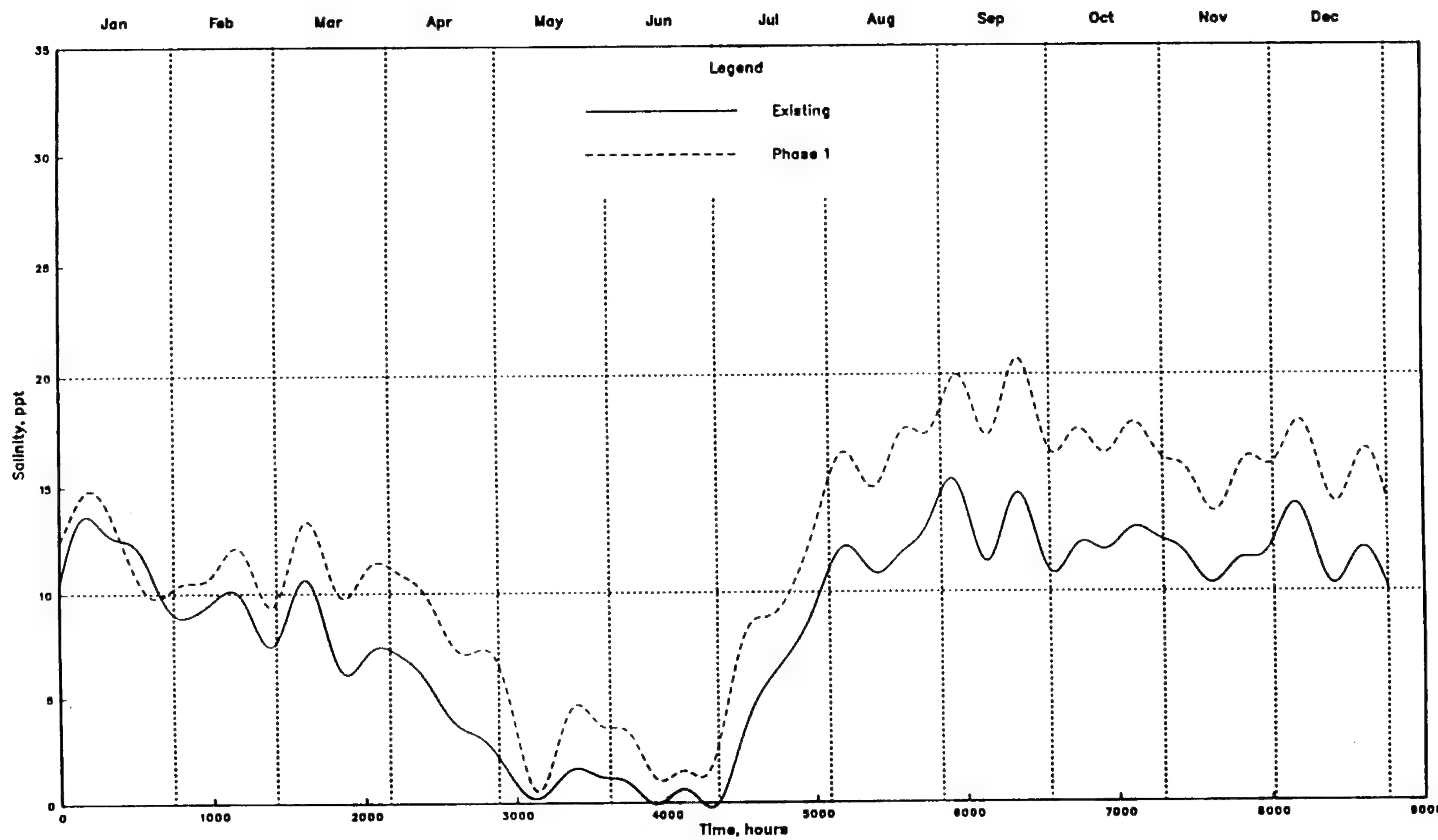
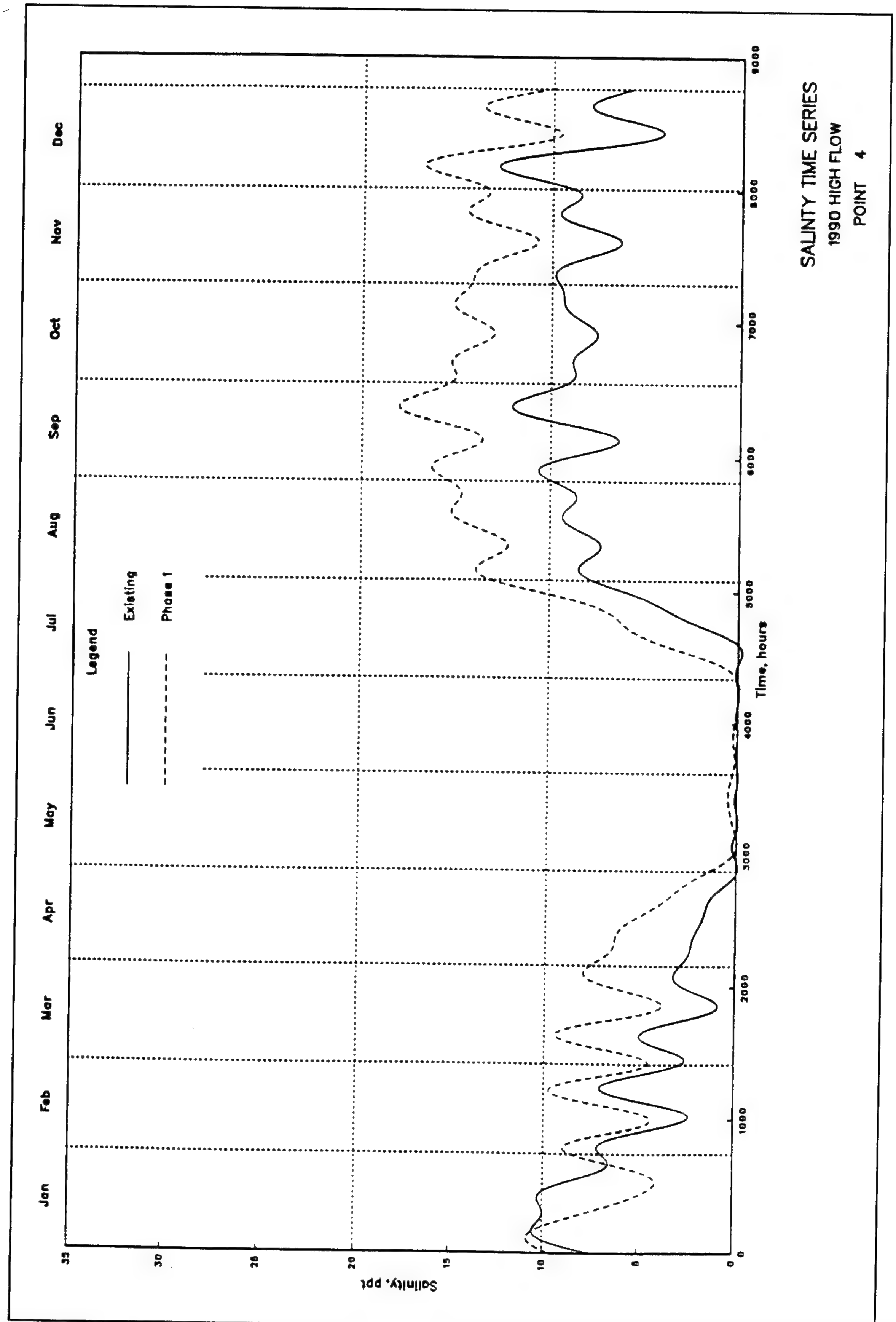
Plate 34



SALINTY TIME SERIES
1990 HIGH FLOW
POINT 3



SALINITY TIME SERIES
1990 HIGH FLOW
POINT 4
Legend
Existing
Phase 1
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Salinity, ppt
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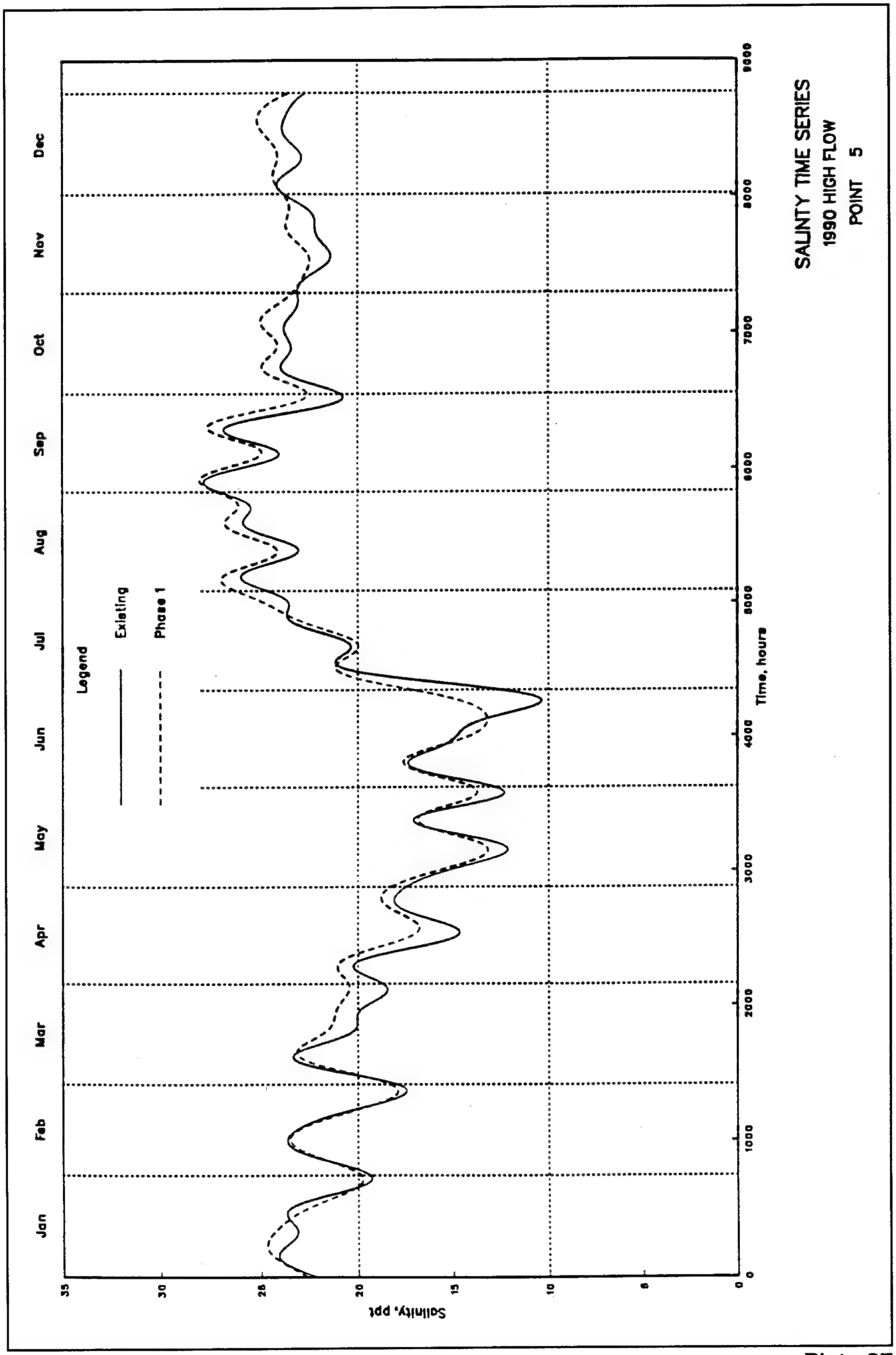
Plate 36



SALINTY TIME SERIES
1990 HIGH FLOW
POINT 5
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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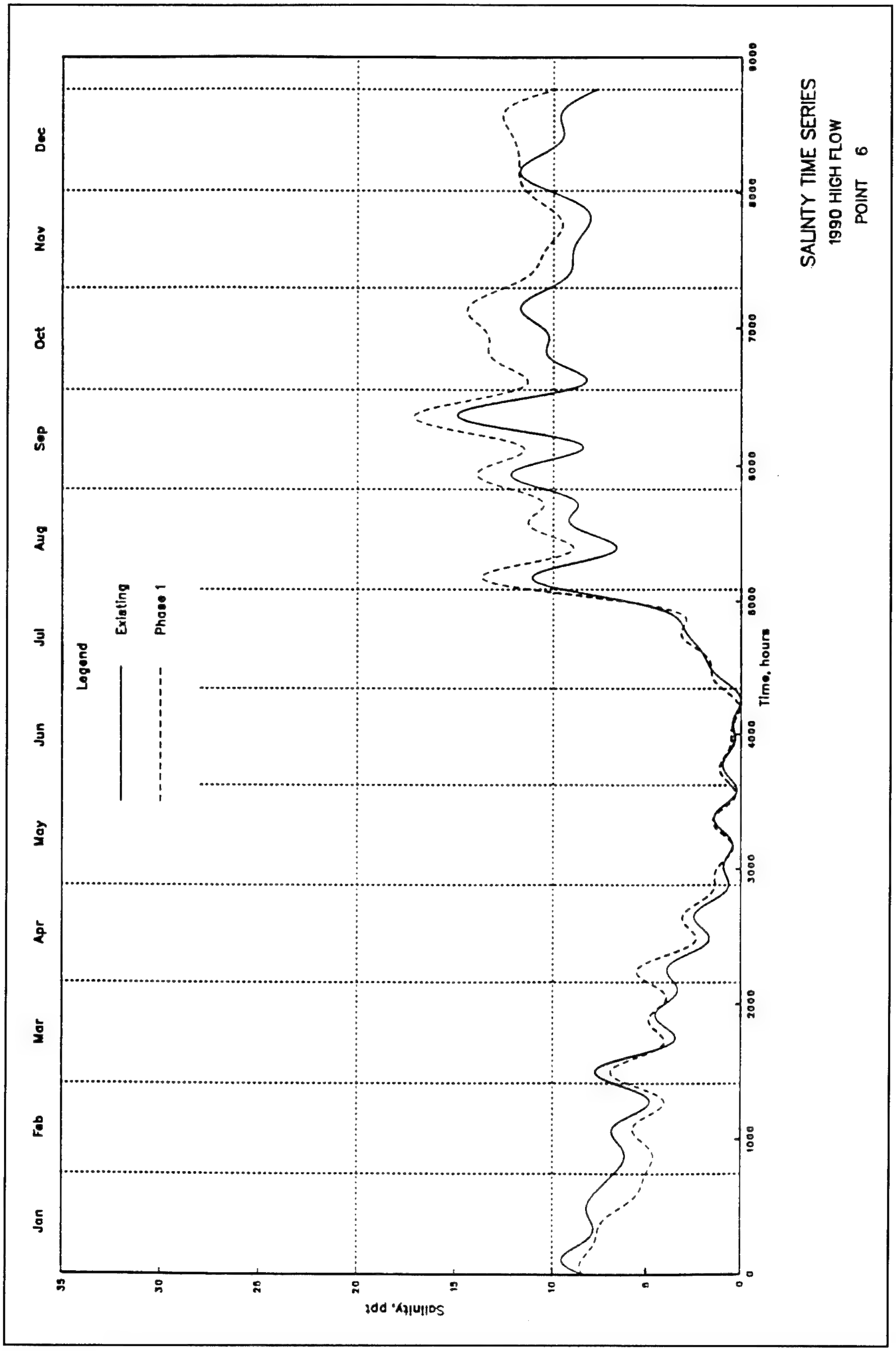
SALINTY TIME SERIES
1990 HIGH FLOW
POINT 6
Legend
Existing
Phase 1
Time, hours
Salinity, ppt
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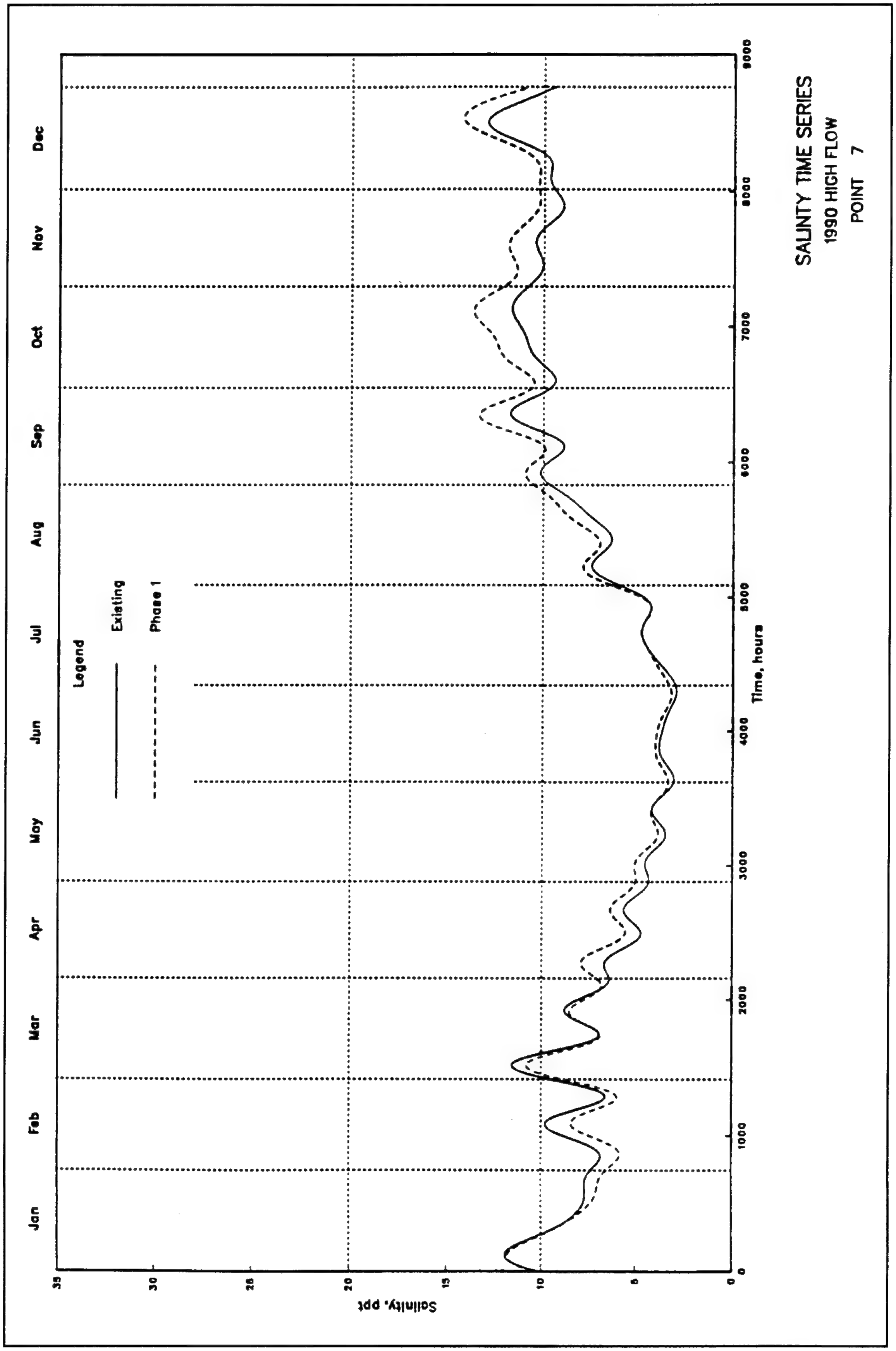
Plate 38



SALINTY TIME SERIES
1990 HIGH FLOW
POINT 7
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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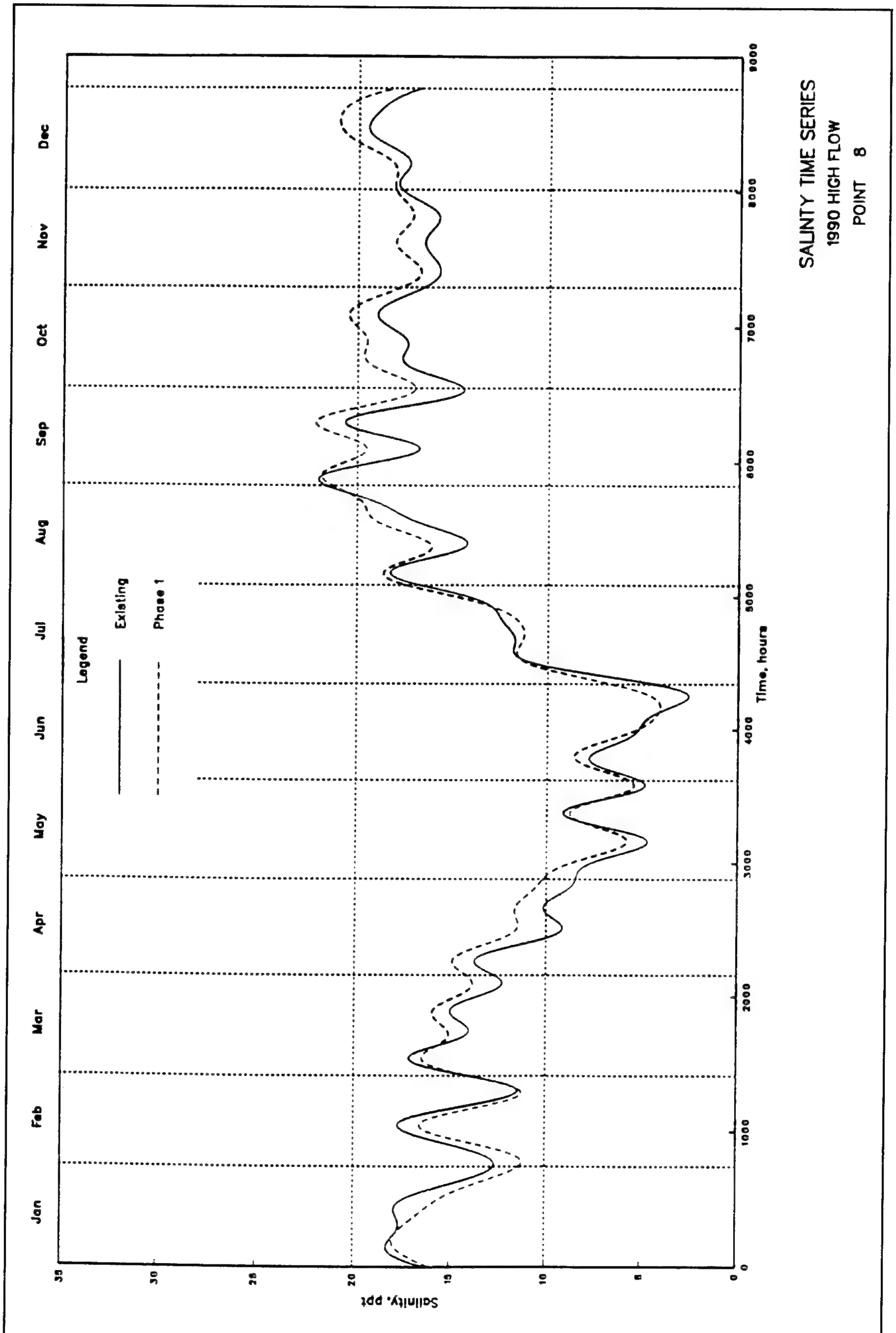

SALINITY TIME SERIES
1990 HIGH FLOW
POINT 8
Legend
Existing
Phase 1
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Time, hours
Salinity, ppt
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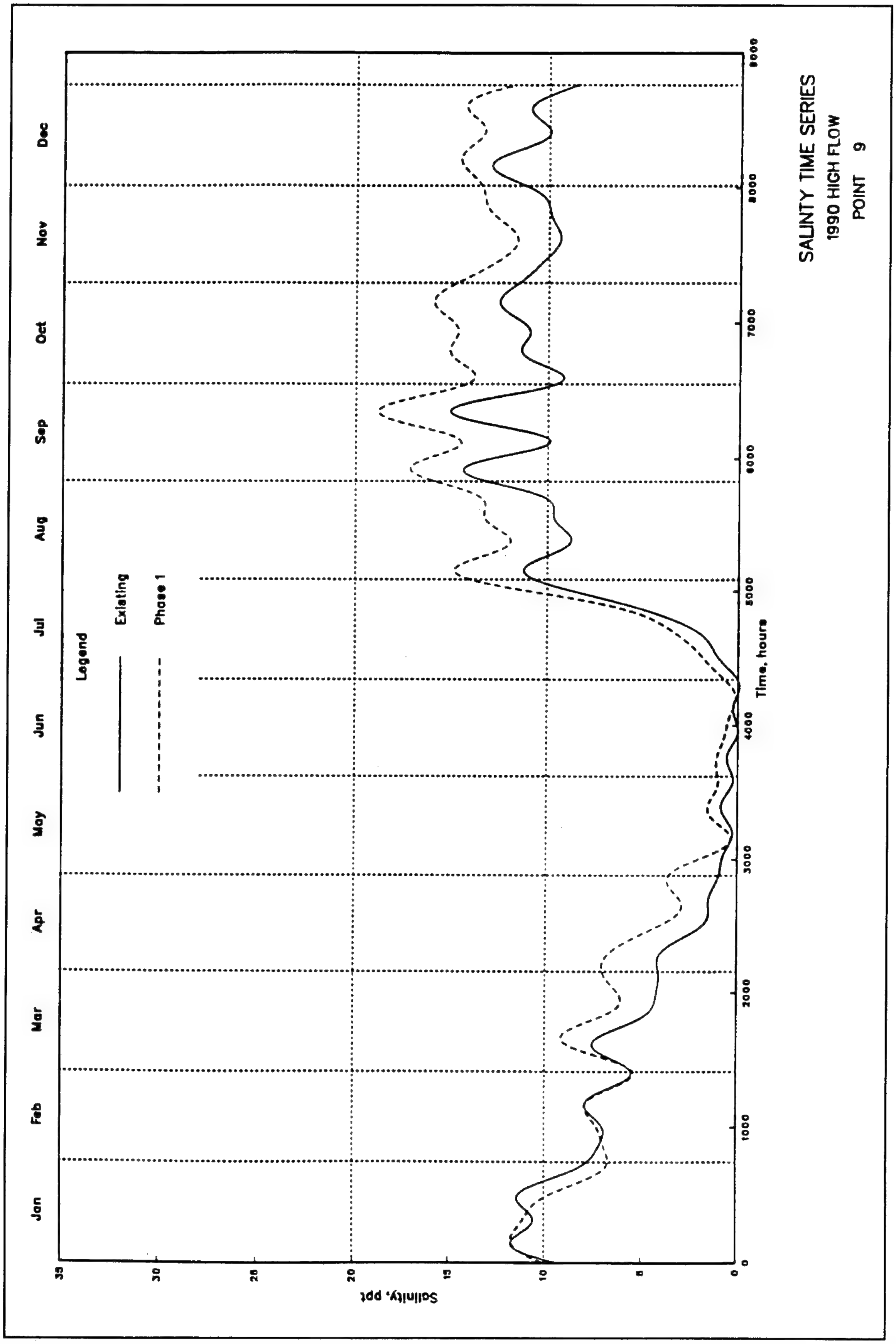
Plate 40



SALINTY TIME SERIES
1990 HIGH FLOW
POINT 9
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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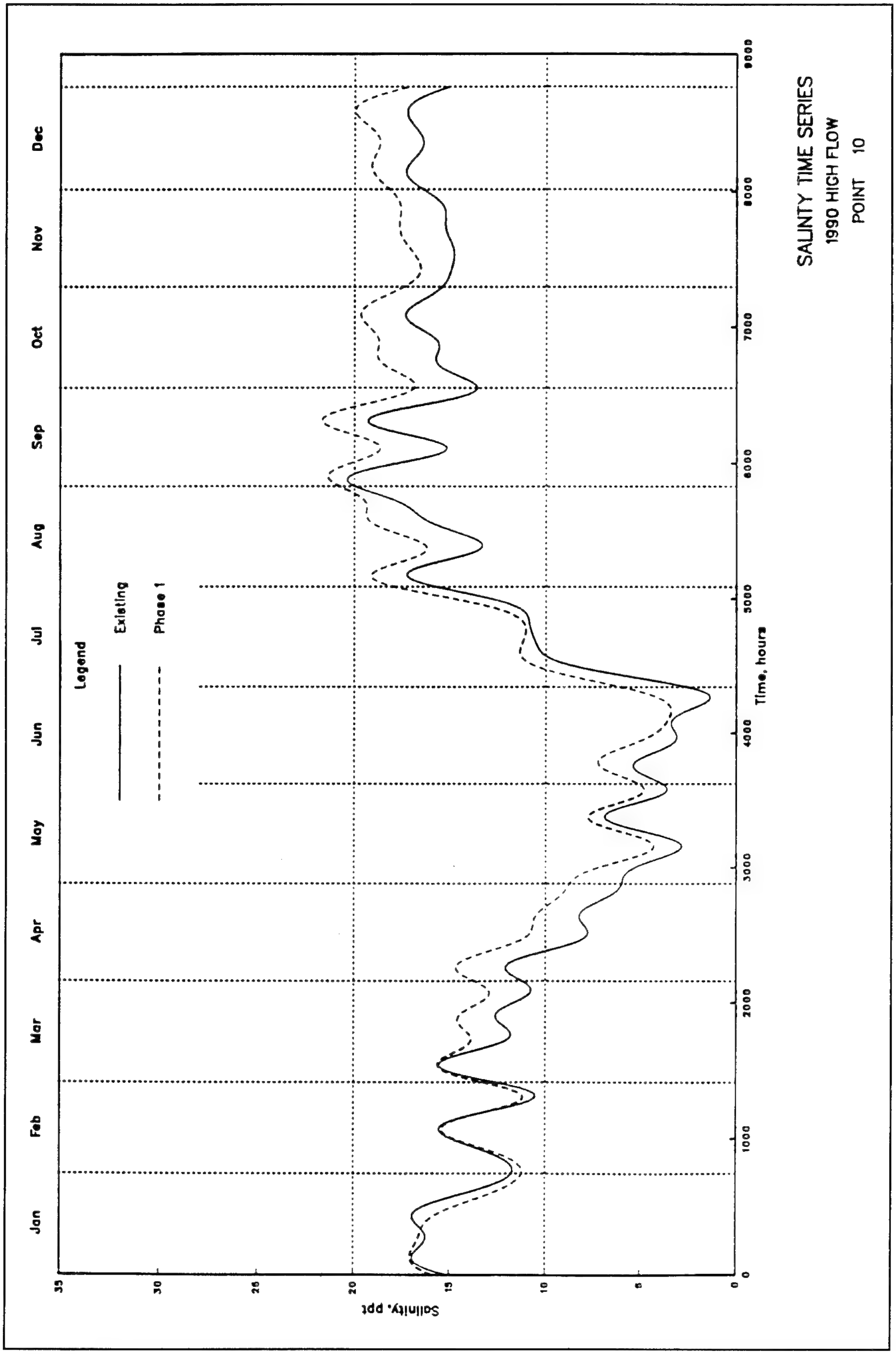
SALINTY TIME SERIES
1990 HIGH FLOW
POINT 10
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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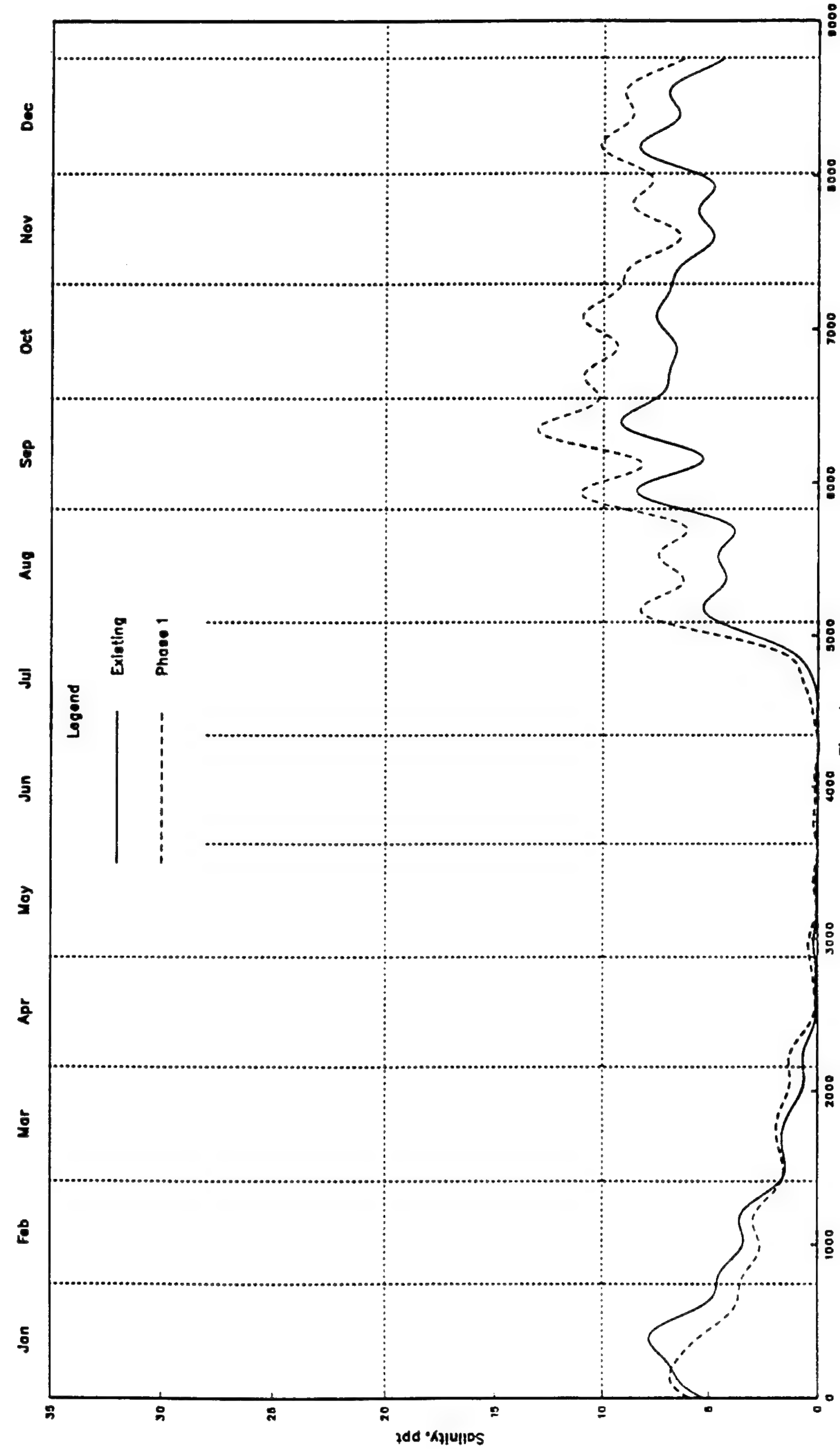
Plate 42



SALINTY TIME SERIES
1990 HIGH FLOW
POINT 11

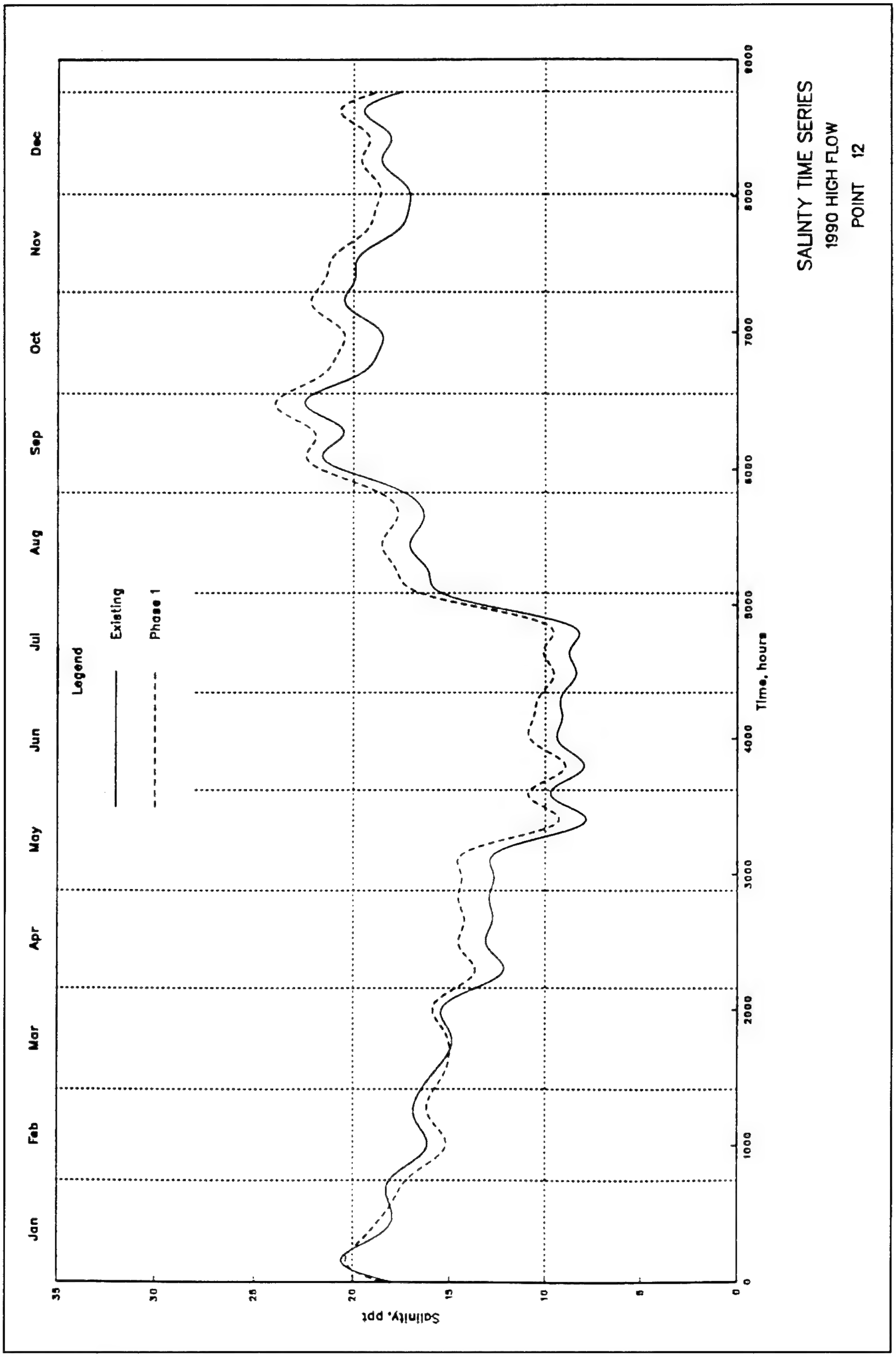

SALINTY TIME SERIES
1990 HIGH FLOW
POINT 12
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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Plate 44

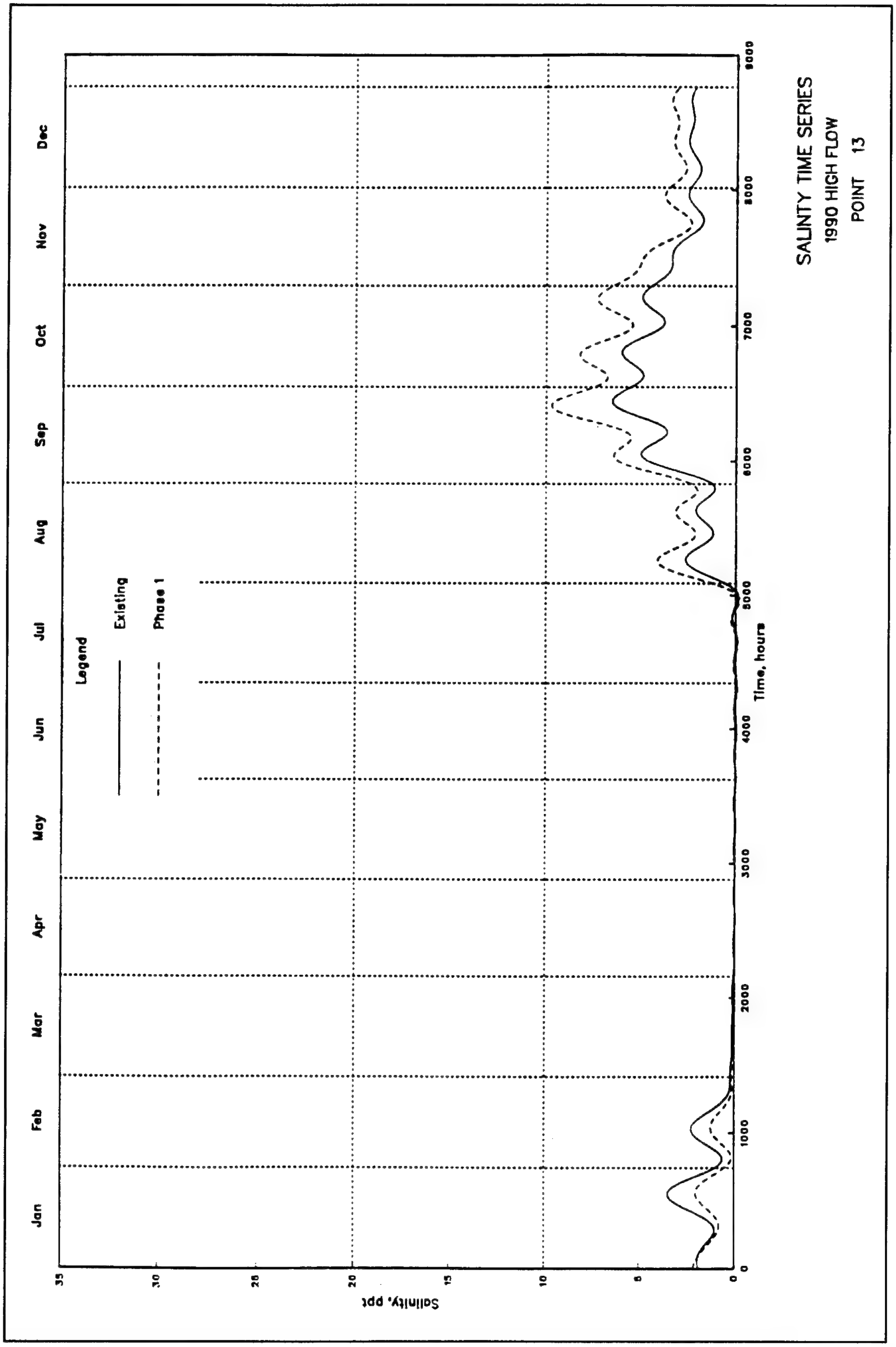
SALINTY TIME SERIES
1990 HIGH FLOW
POINT 13
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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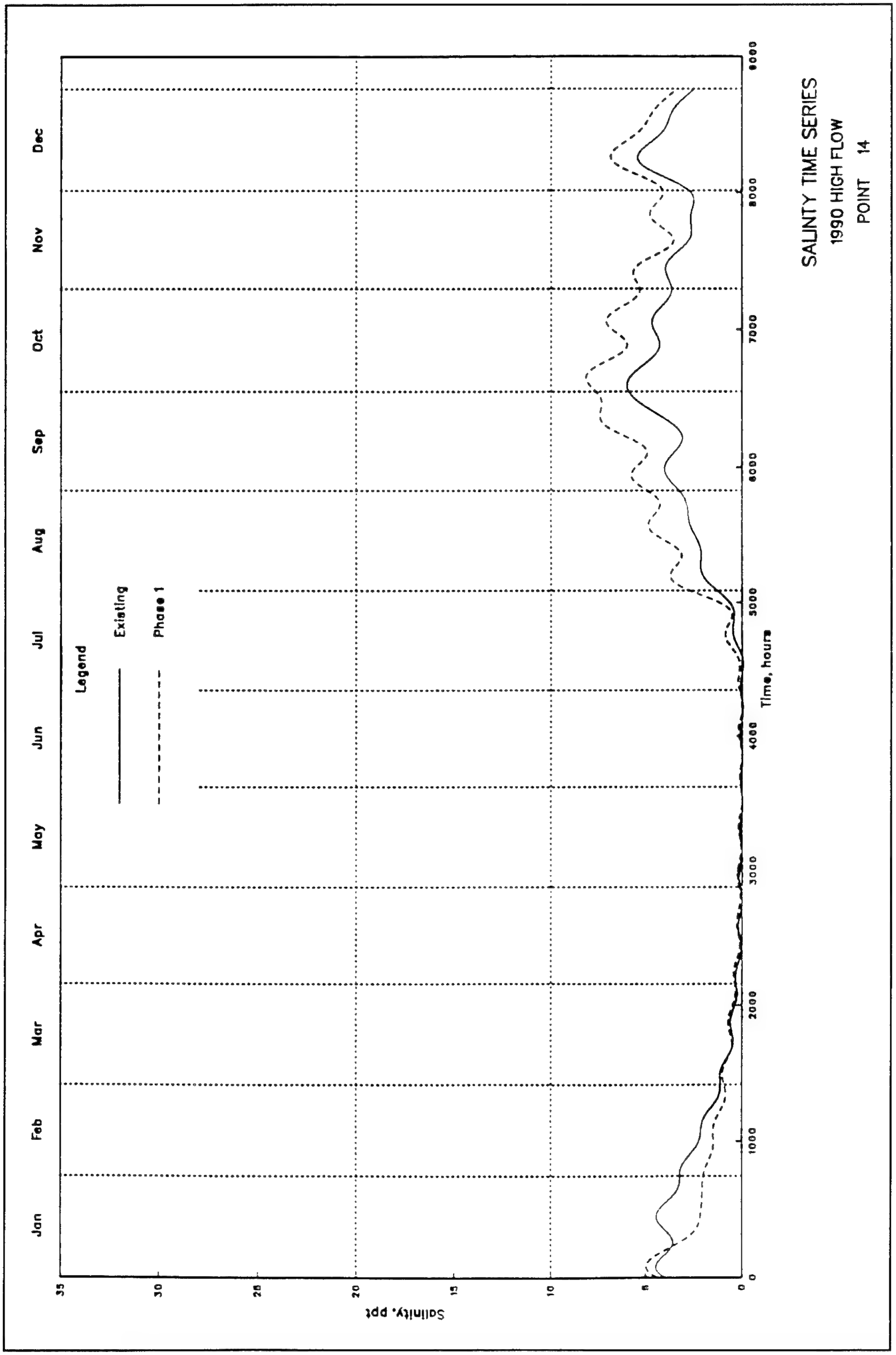
Plate 45



SALINTY TIME SERIES
1990 HIGH FLOW
POINT 14
Legend
Existing
Phase 1
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Nov
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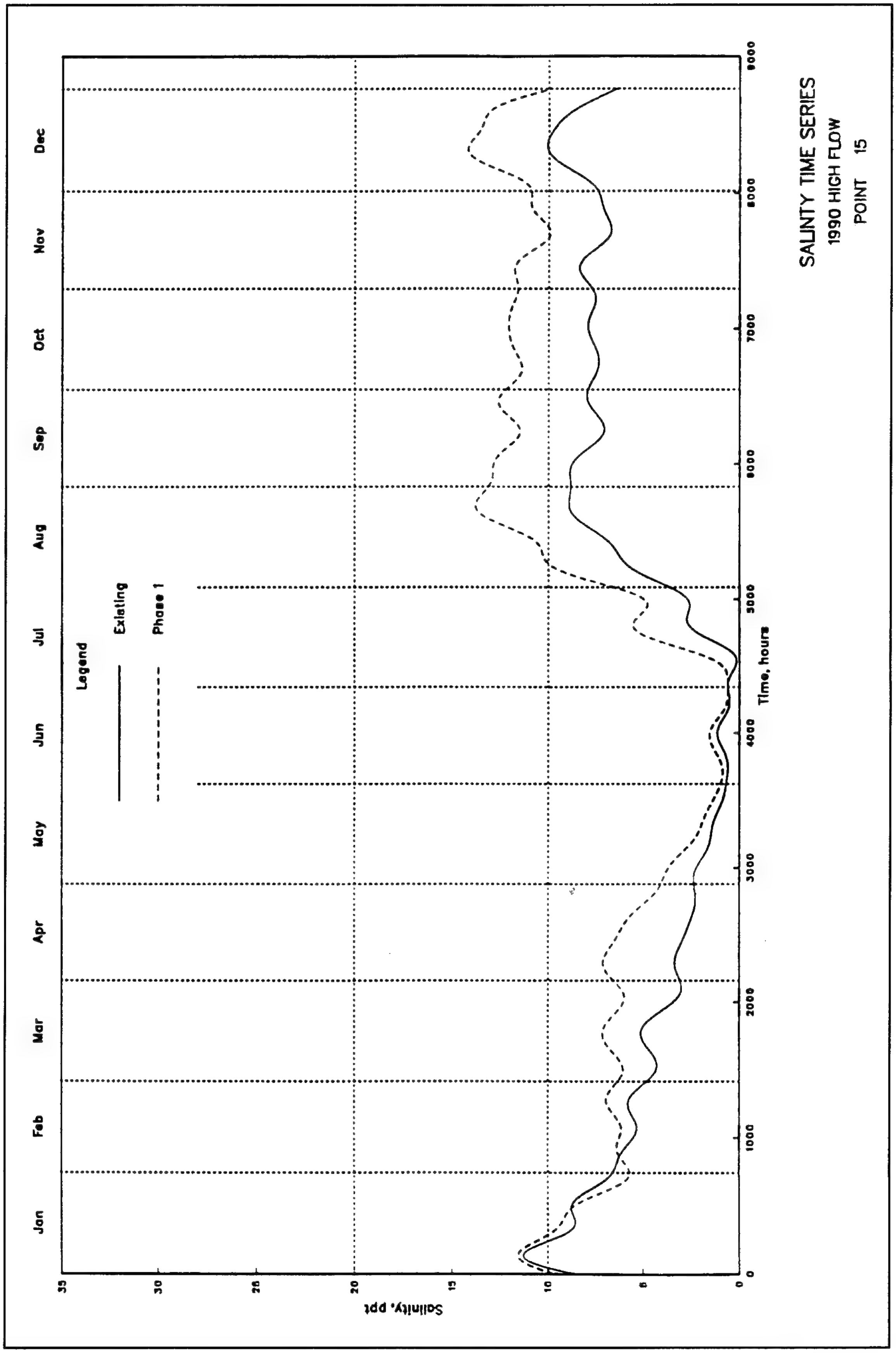
Time, hours
Salinity, ppt

Plate 46


SALINTY TIME SERIES
1990 HIGH FLOW
POINT 15
Legend
Existing
Phase 1
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Salinity, ppt
Time, hours
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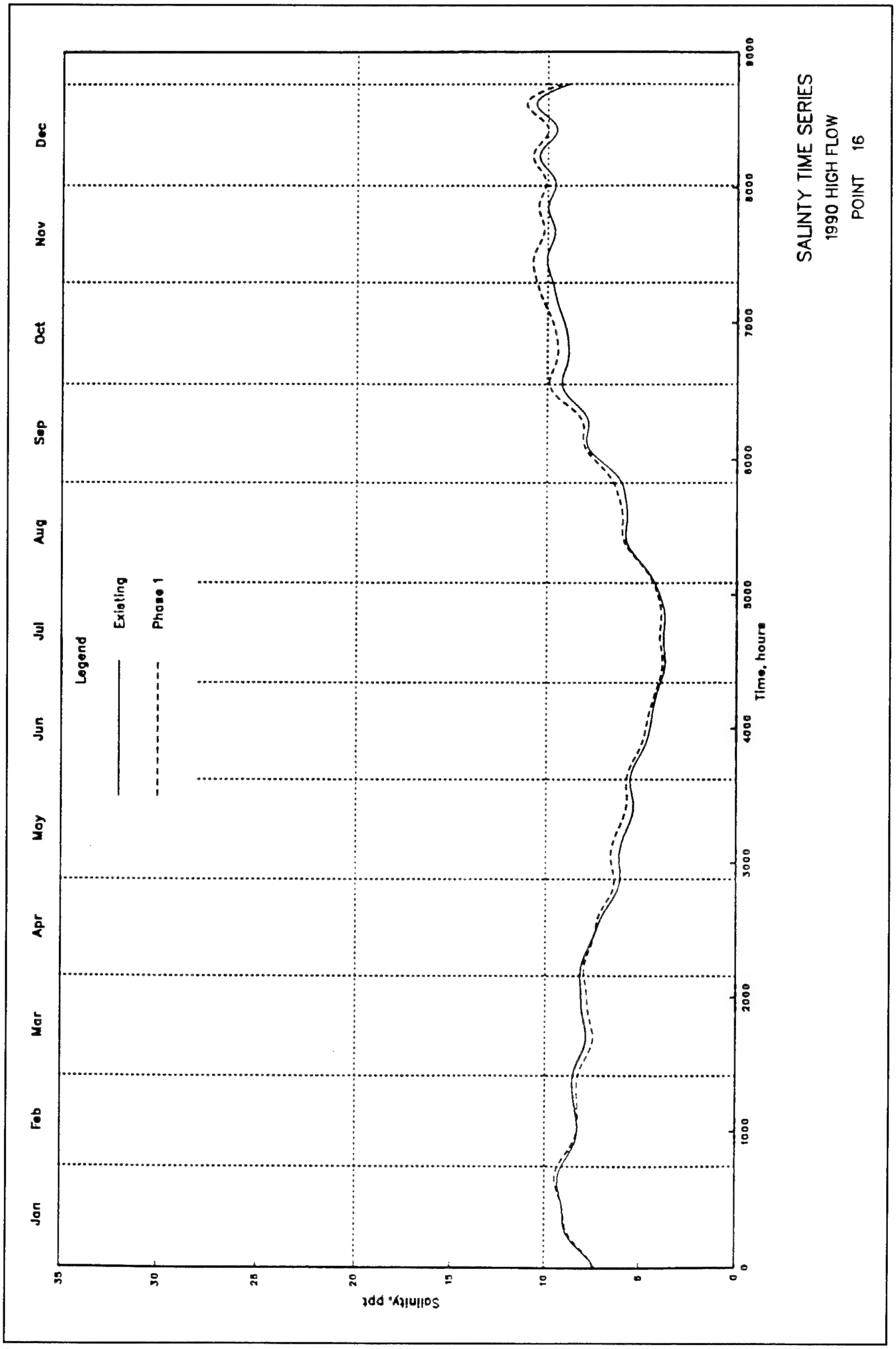
Plate 47



SALINTY TIME SERIES
1990 HIGH FLOW
POINT 16
Legend
Existing
Phase 1
Time, hours
Salinity, ppt
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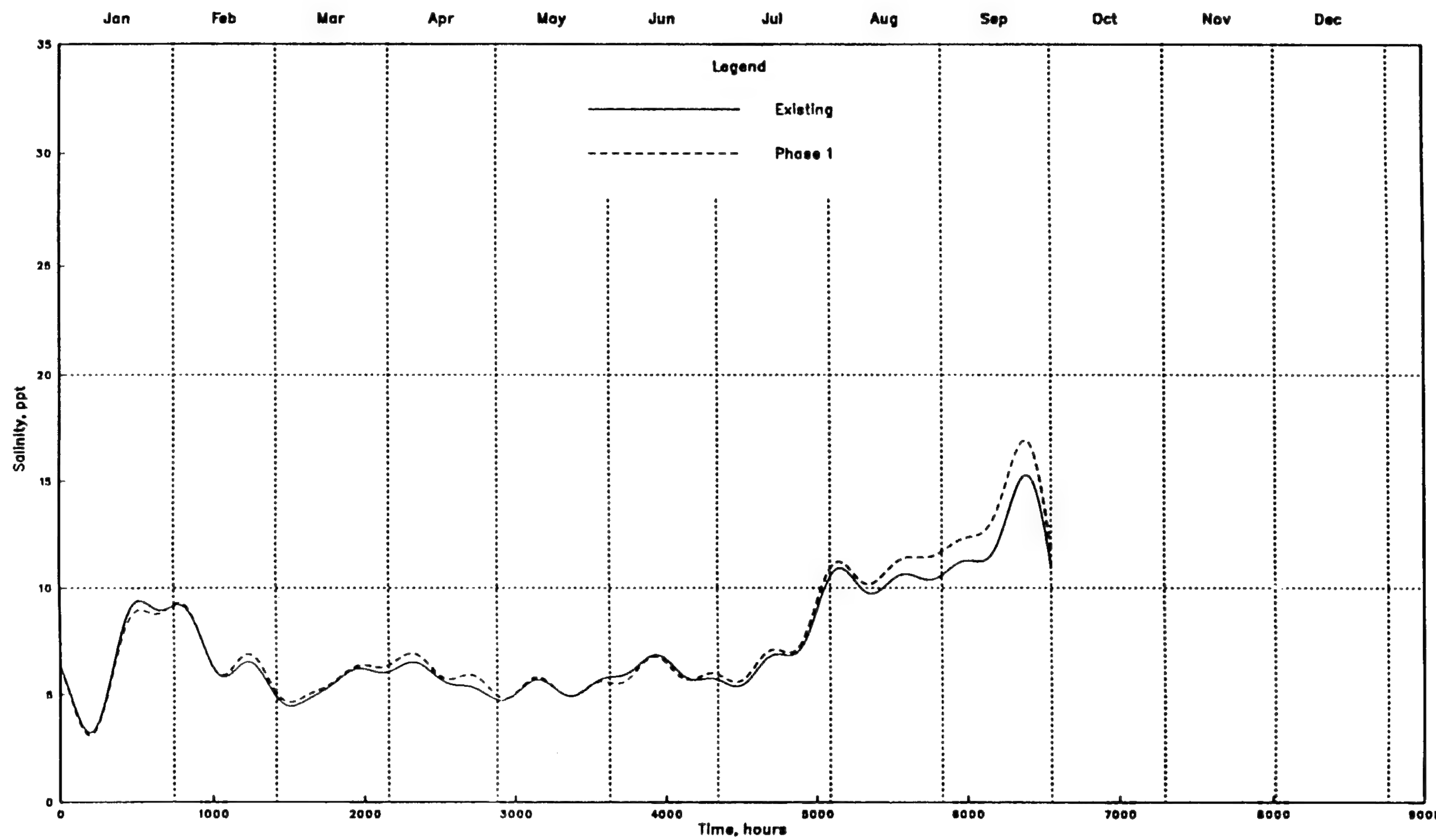
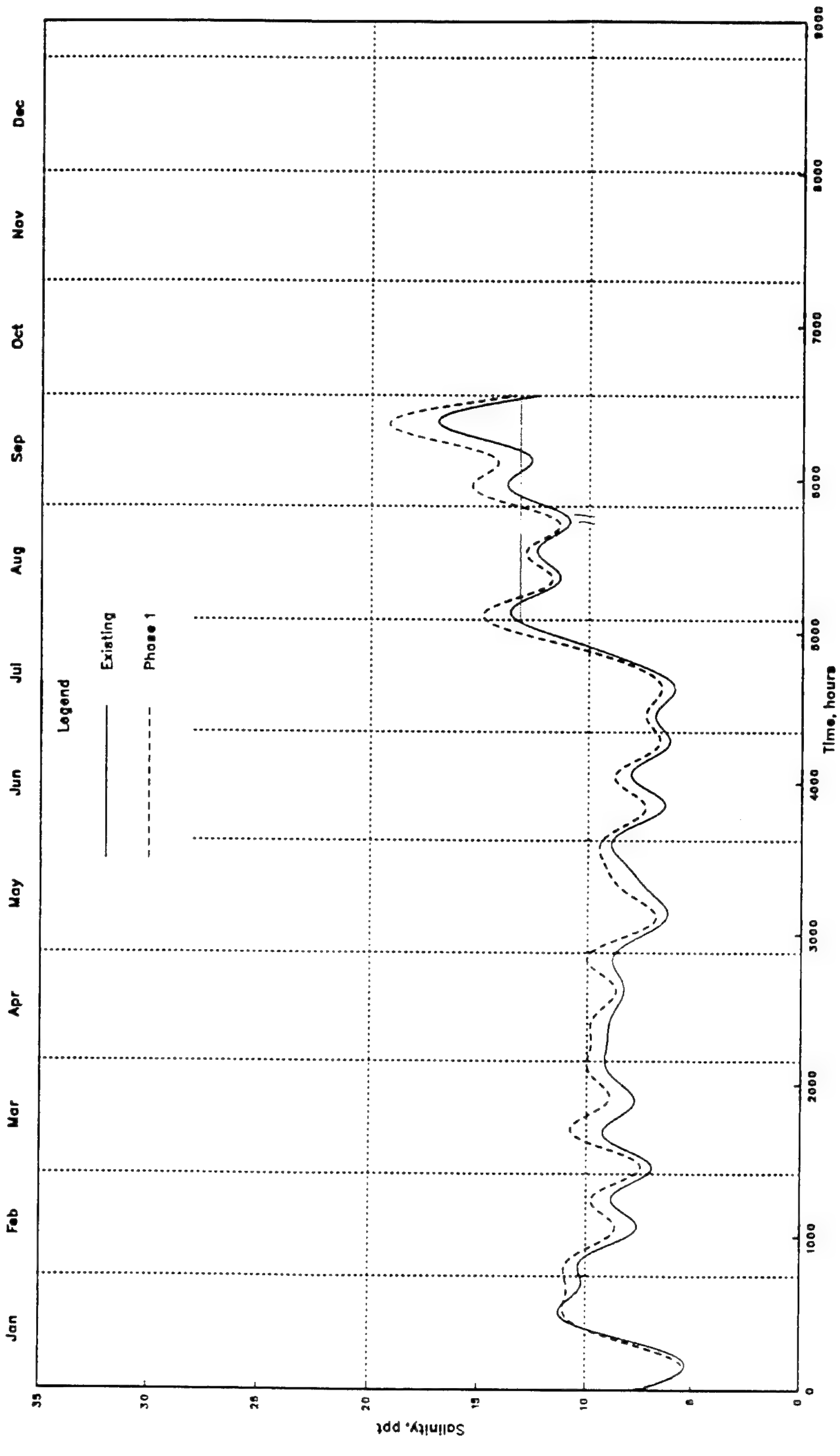
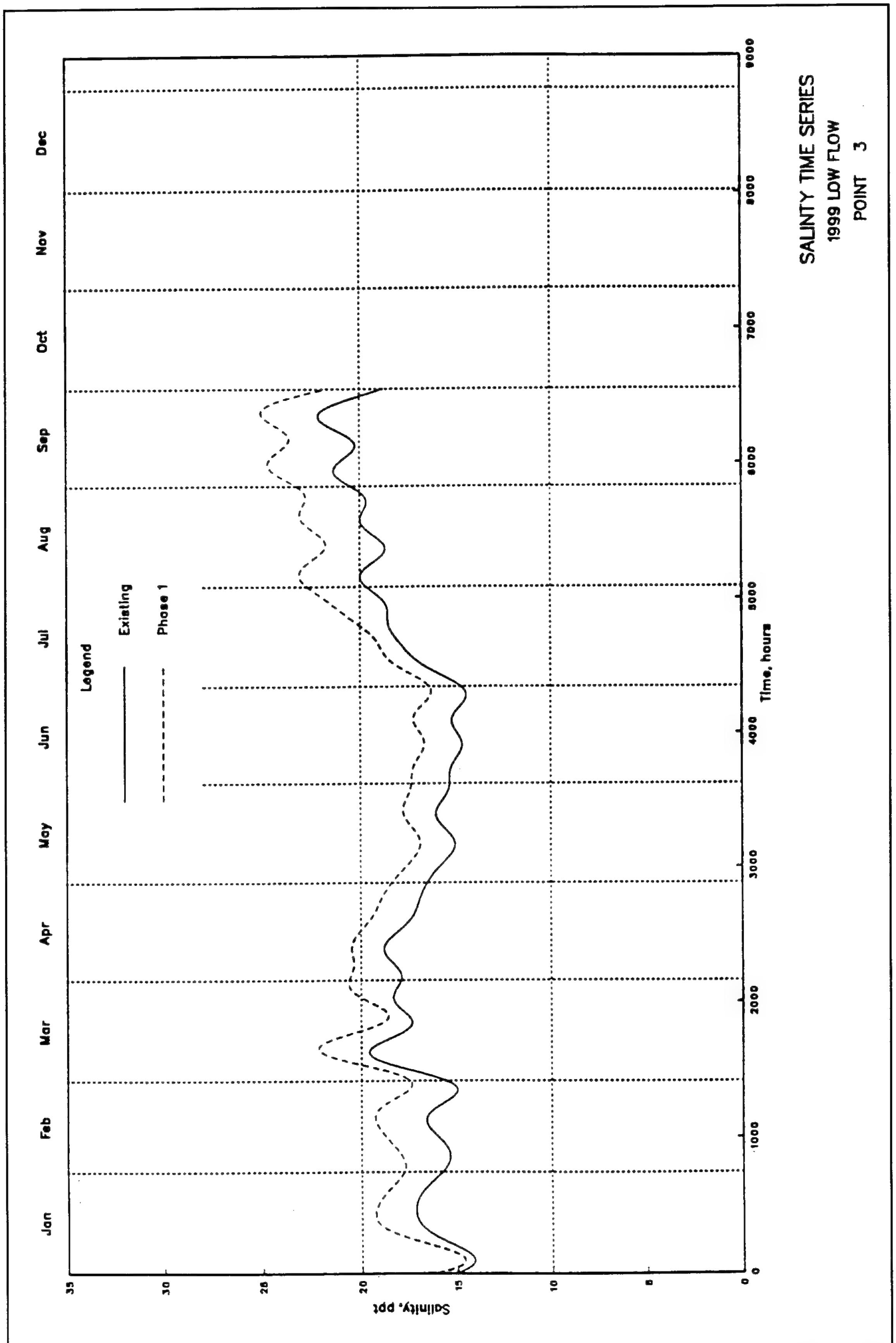
Plate 48



SALINTY TIME SERIES
1999 LOW FLOW
POINT 1



SALINTY TIME SERIES
1999 LOW FLOW
POINT 2



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Legend
Existing
Phase 1
Salinity, ppt
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Time, hours
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SALINTY TIME SERIES
1999 LOW FLOW
POINT 3

Plate 51

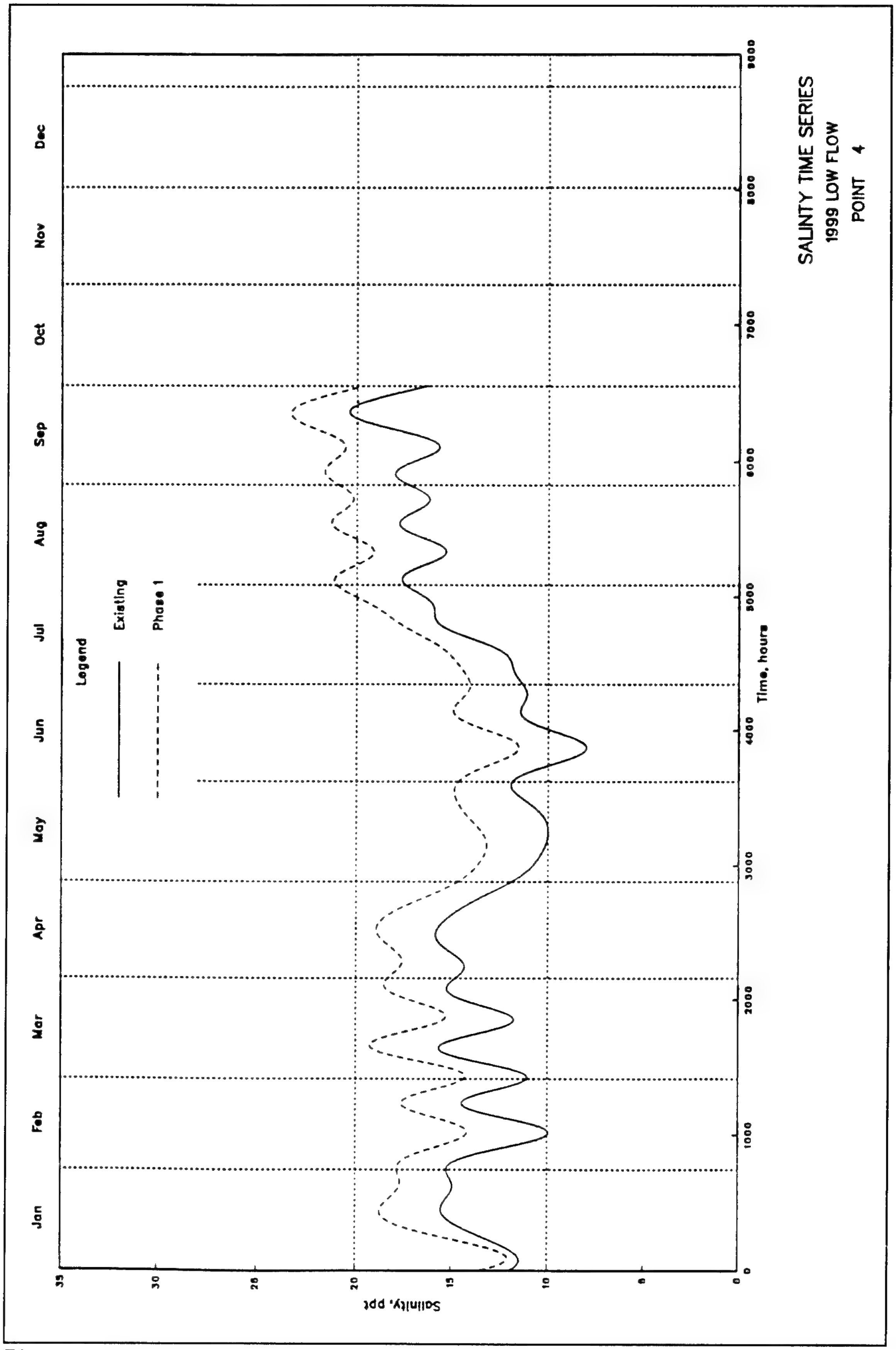
SALINTY TIME SERIES
1999 LOW FLOW
POINT 4
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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Plate 52

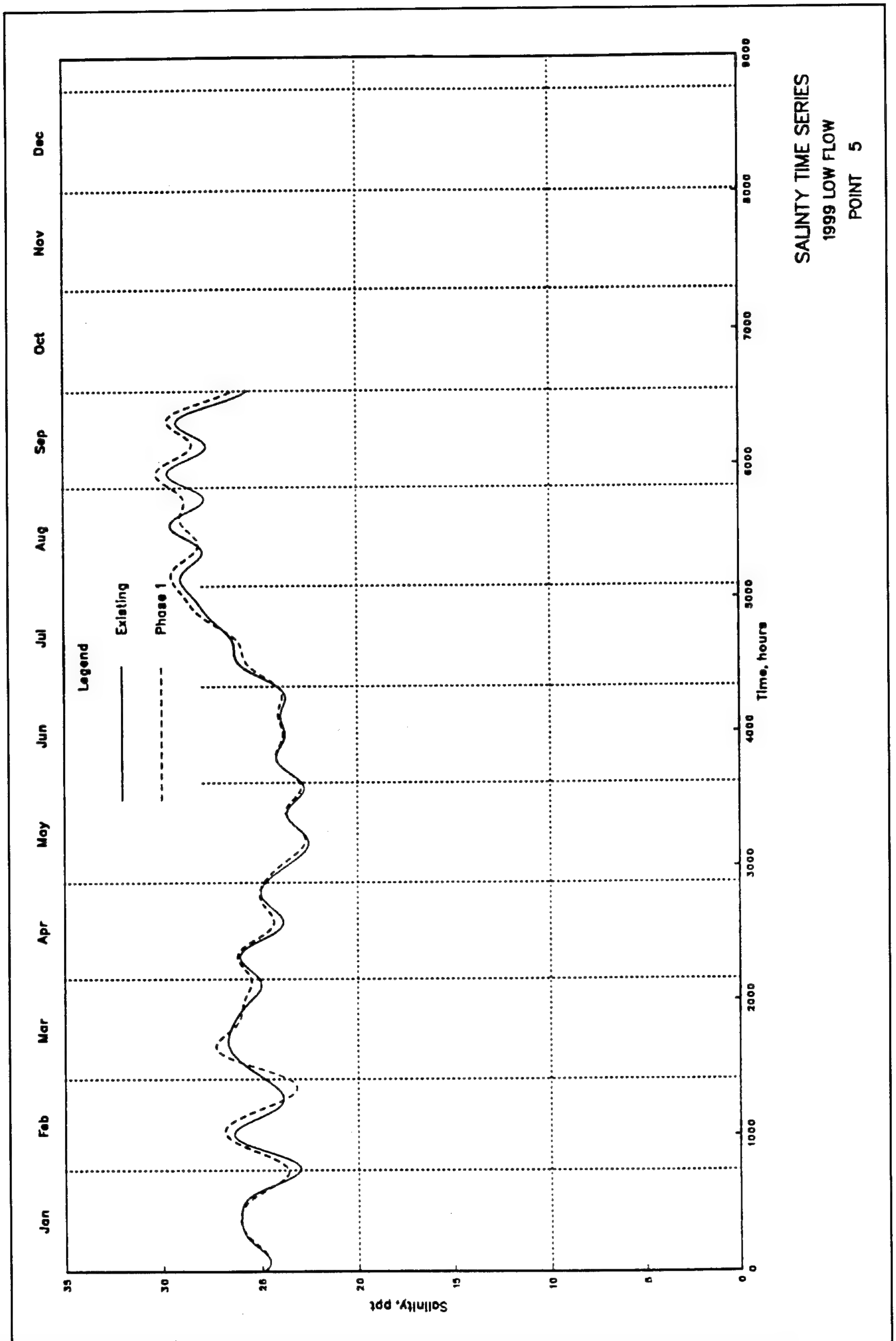
SALINTY TIME SERIES
1999 LOW FLOW
POINT 5
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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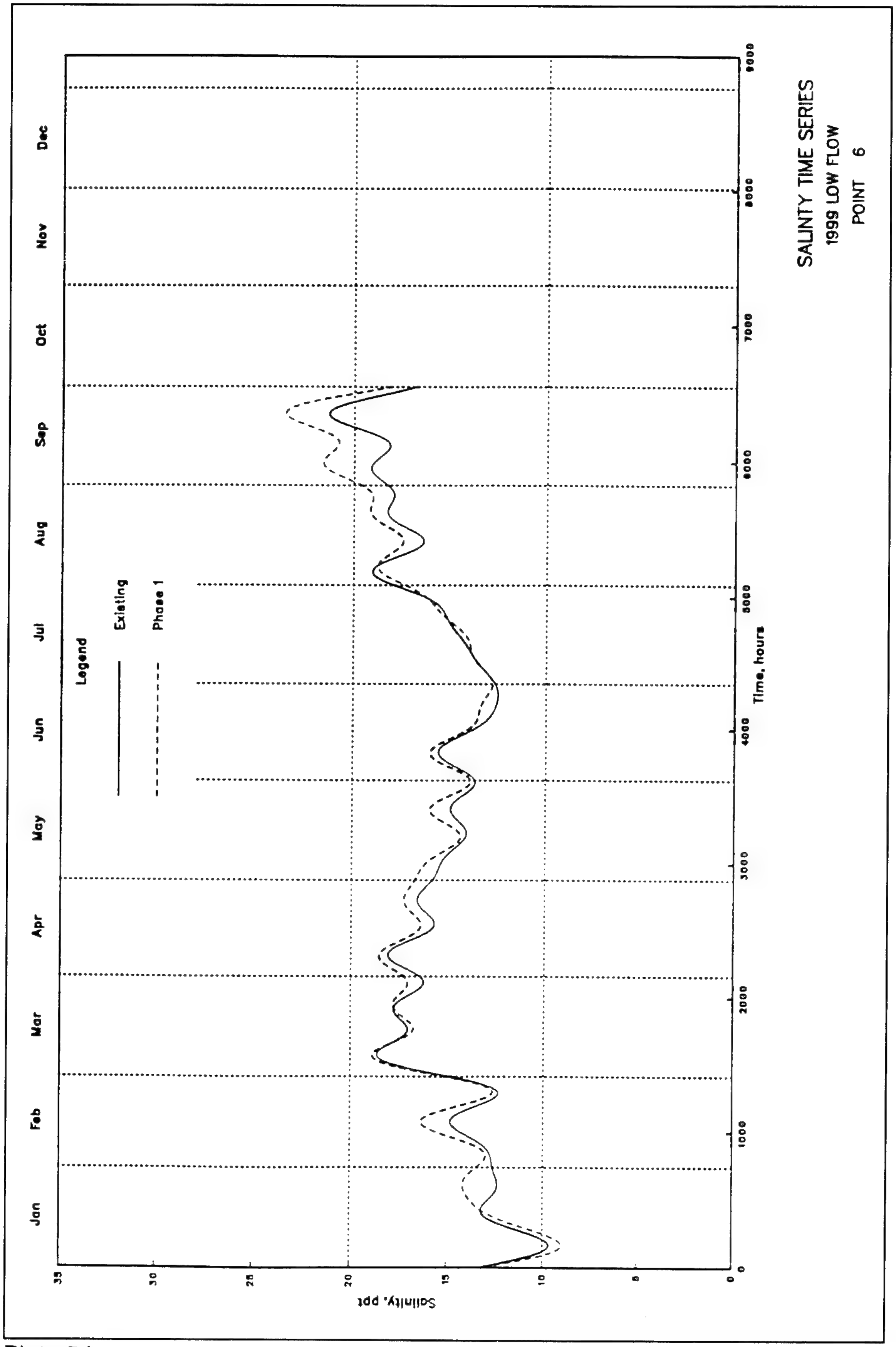
Plate 53


SALINTY TIME SERIES
1999 LOW FLOW
POINT 6
Legend
Existing
Phase 1
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Salinity, ppt
Time, hours
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Plate 54

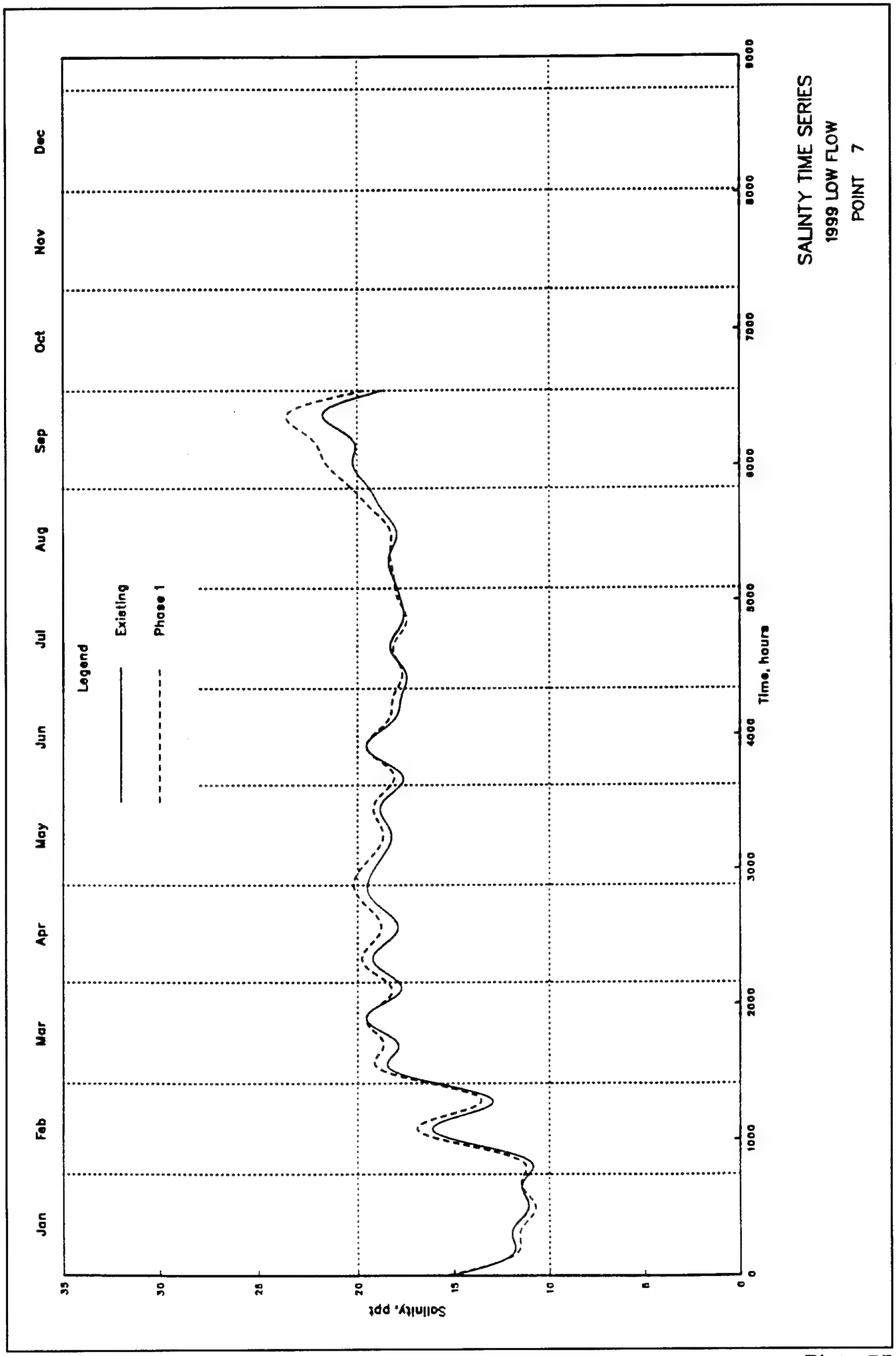
SALINTY TIME SERIES
1999 LOW FLOW
POINT 7
Legend
Existing
Phase 1
Time, hours
Salinity, ppt
Jan
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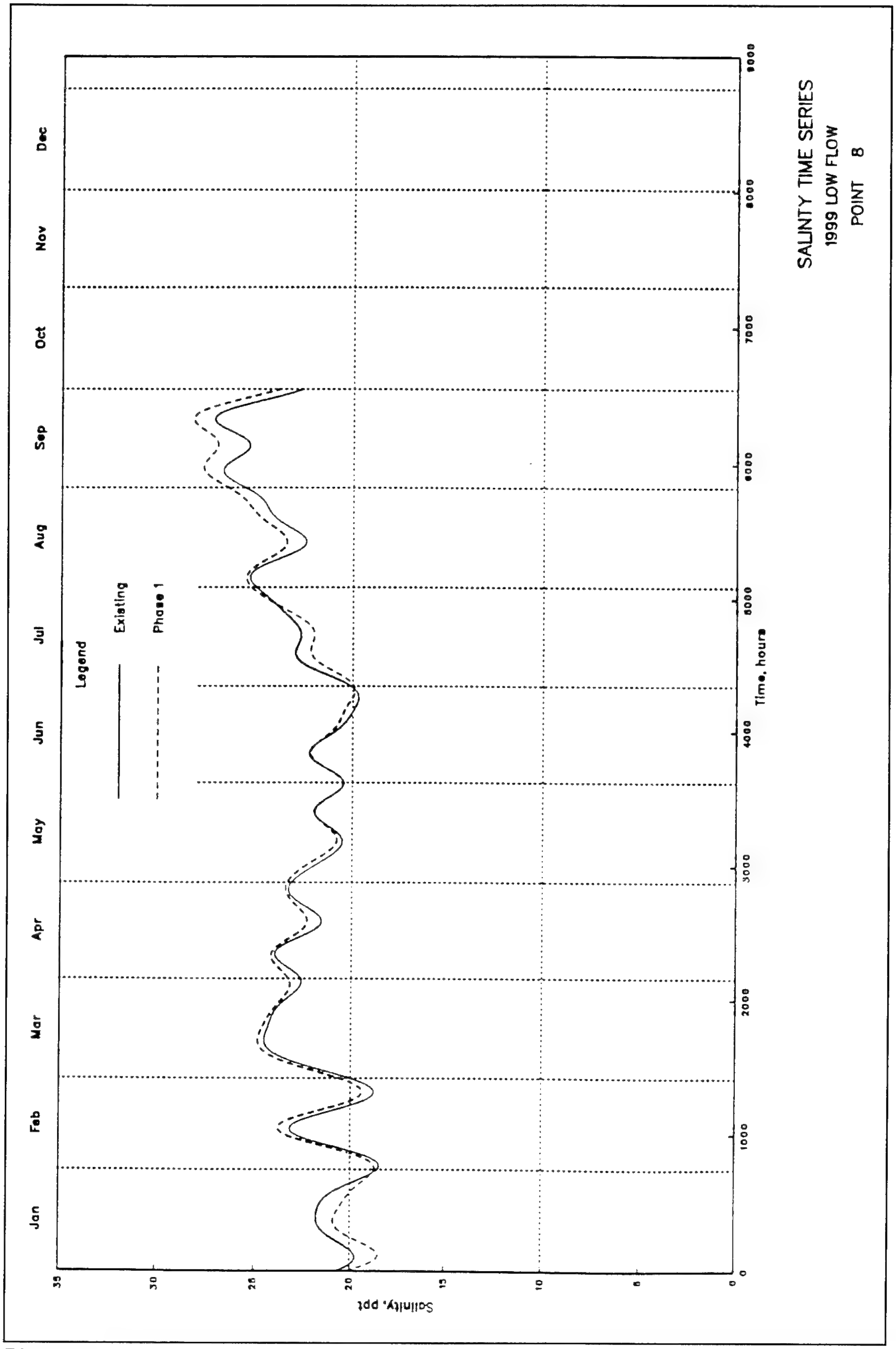
Plate 55



SALINTY TIME SERIES
1999 LOW FLOW
POINT B
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
Jan
Feb
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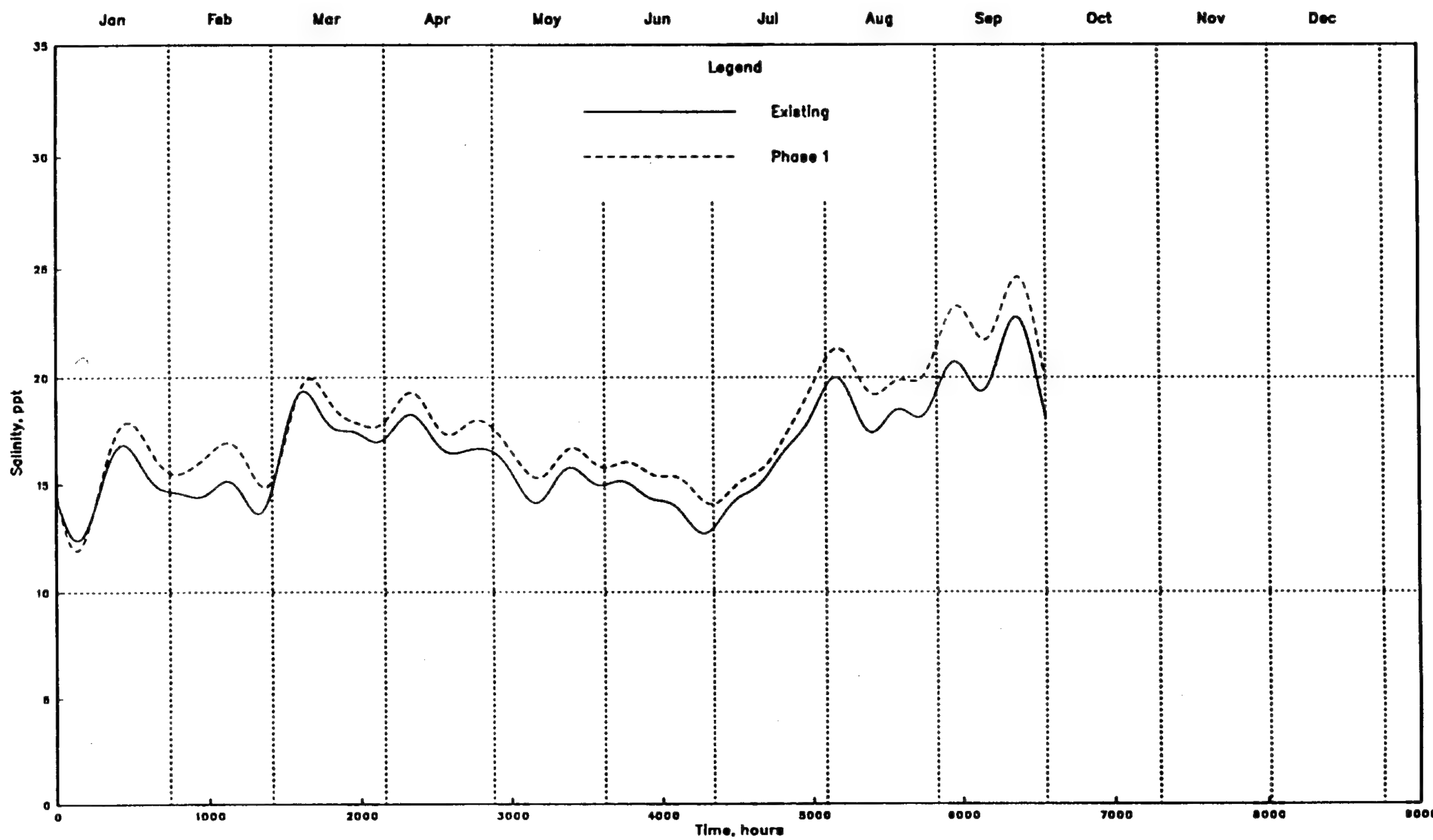
Plate 56



SALINTY TIME SERIES
1999 LOW FLOW
POINT 9

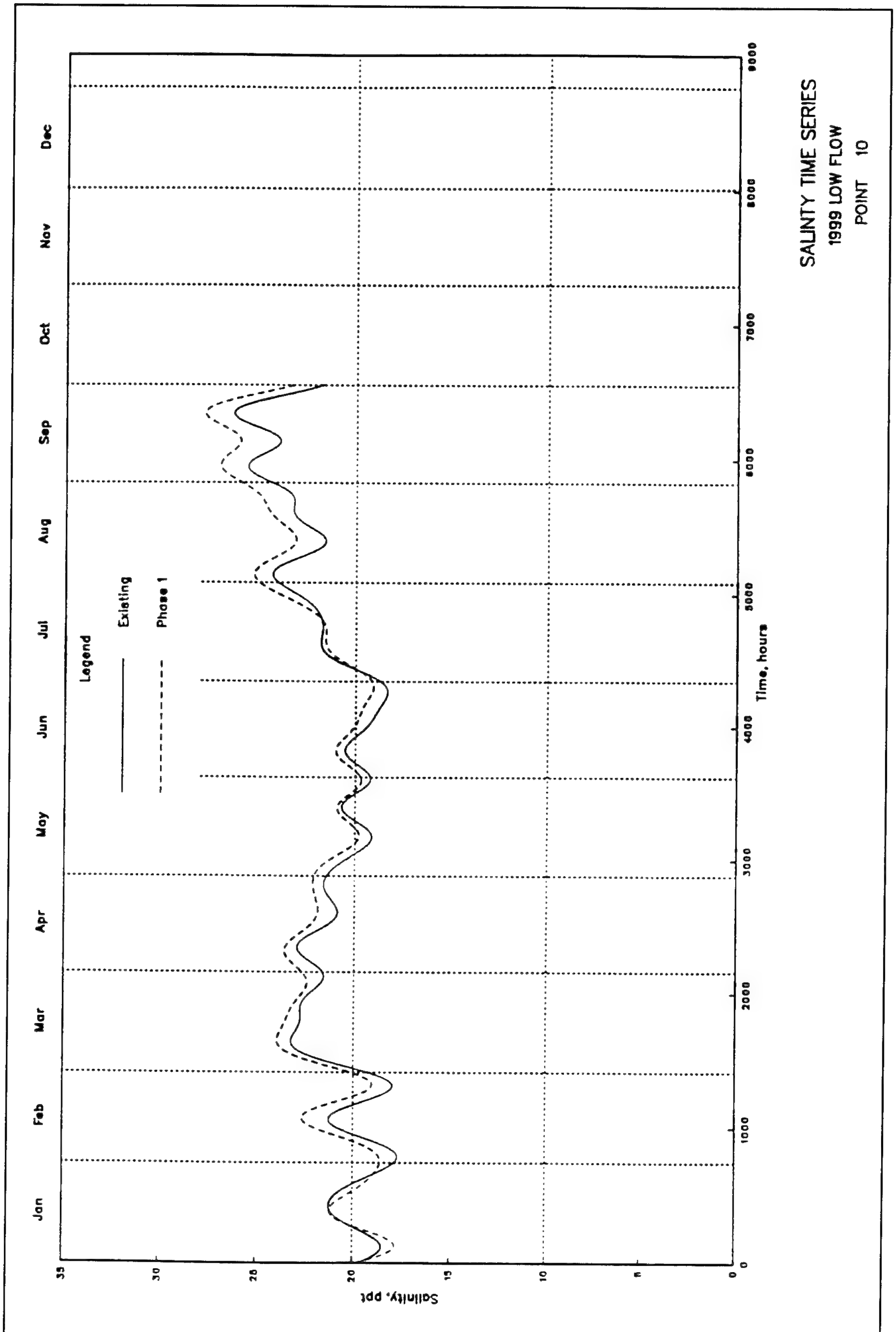

SALINITY TIME SERIES
1999 LOW FLOW
POINT 10
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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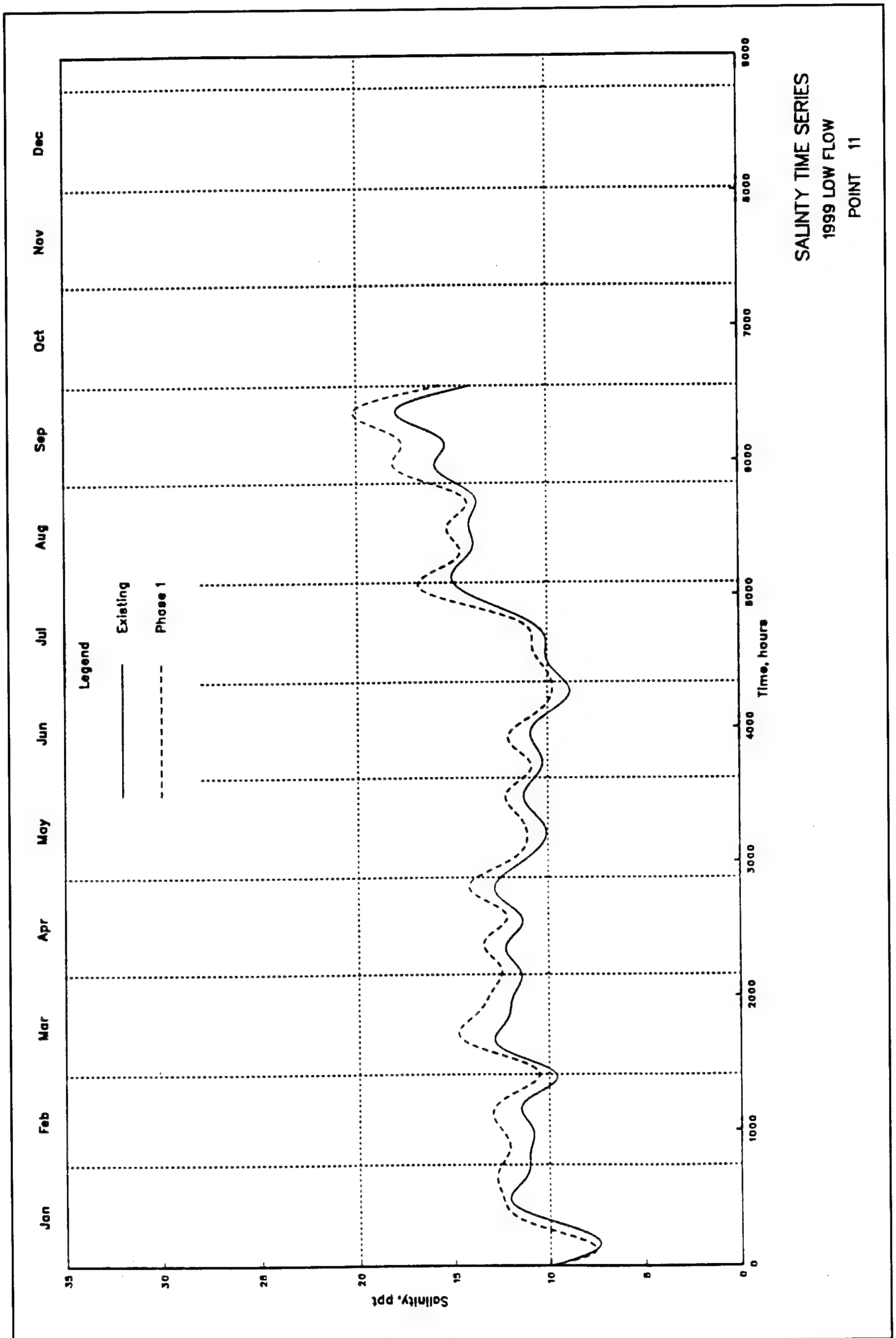
Plate 58


SALINTY TIME SERIES
1999 LOW FLOW
POINT 11
Legend
Existing
Phase 1
Time, hours
Salinity, ppt
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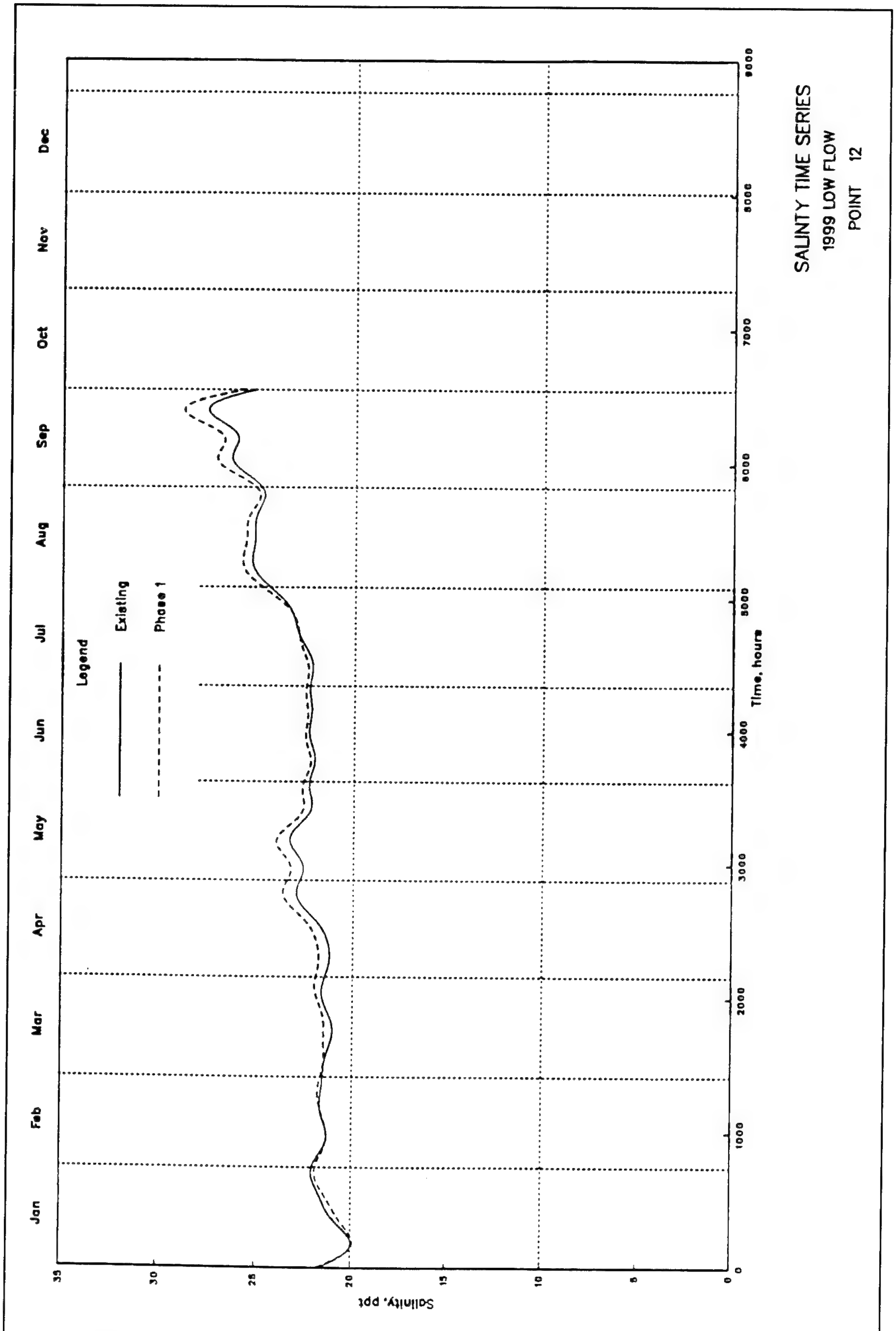
SALINTY TIME SERIES
1999 LOW FLOW
POINT 12
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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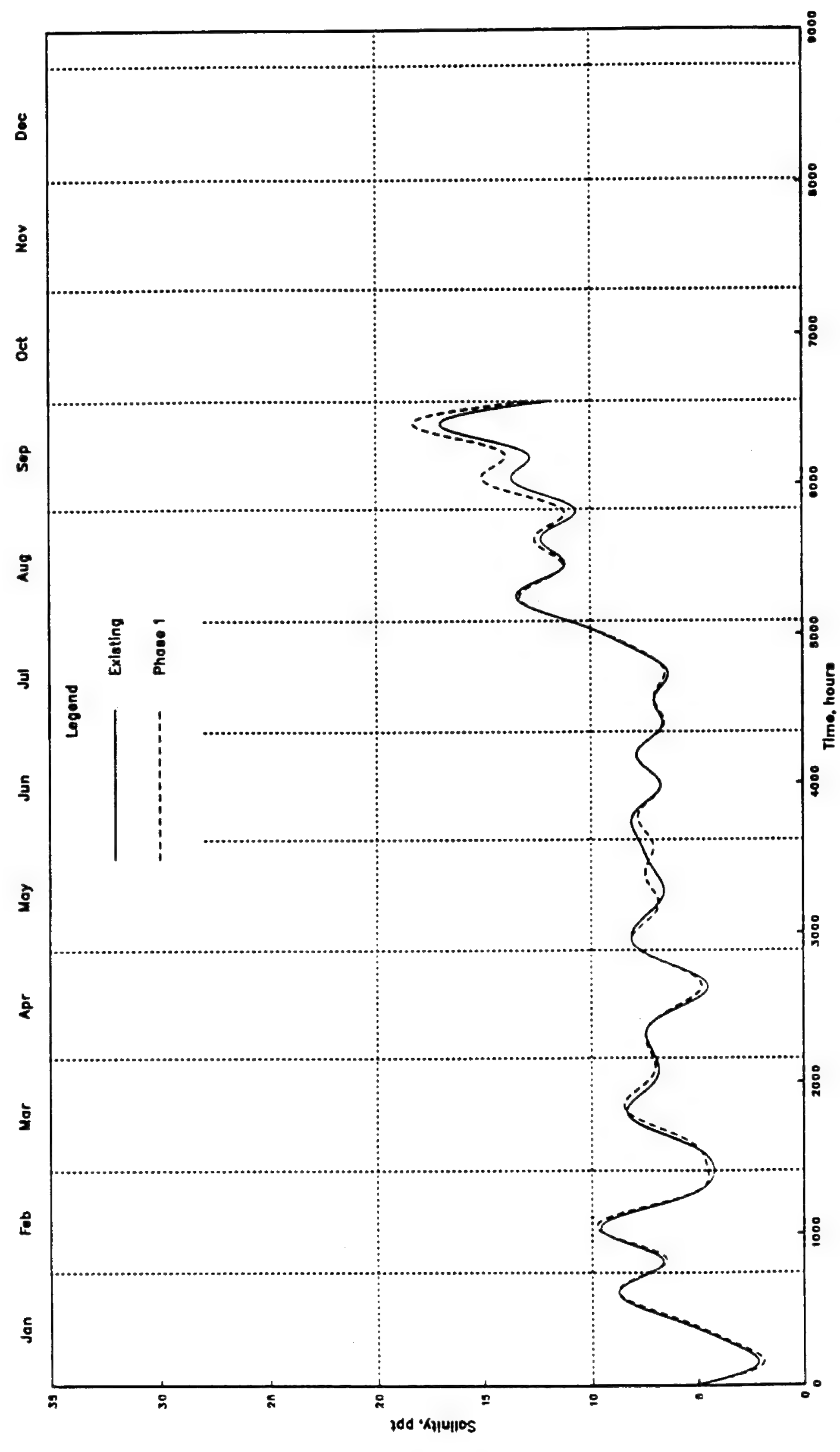
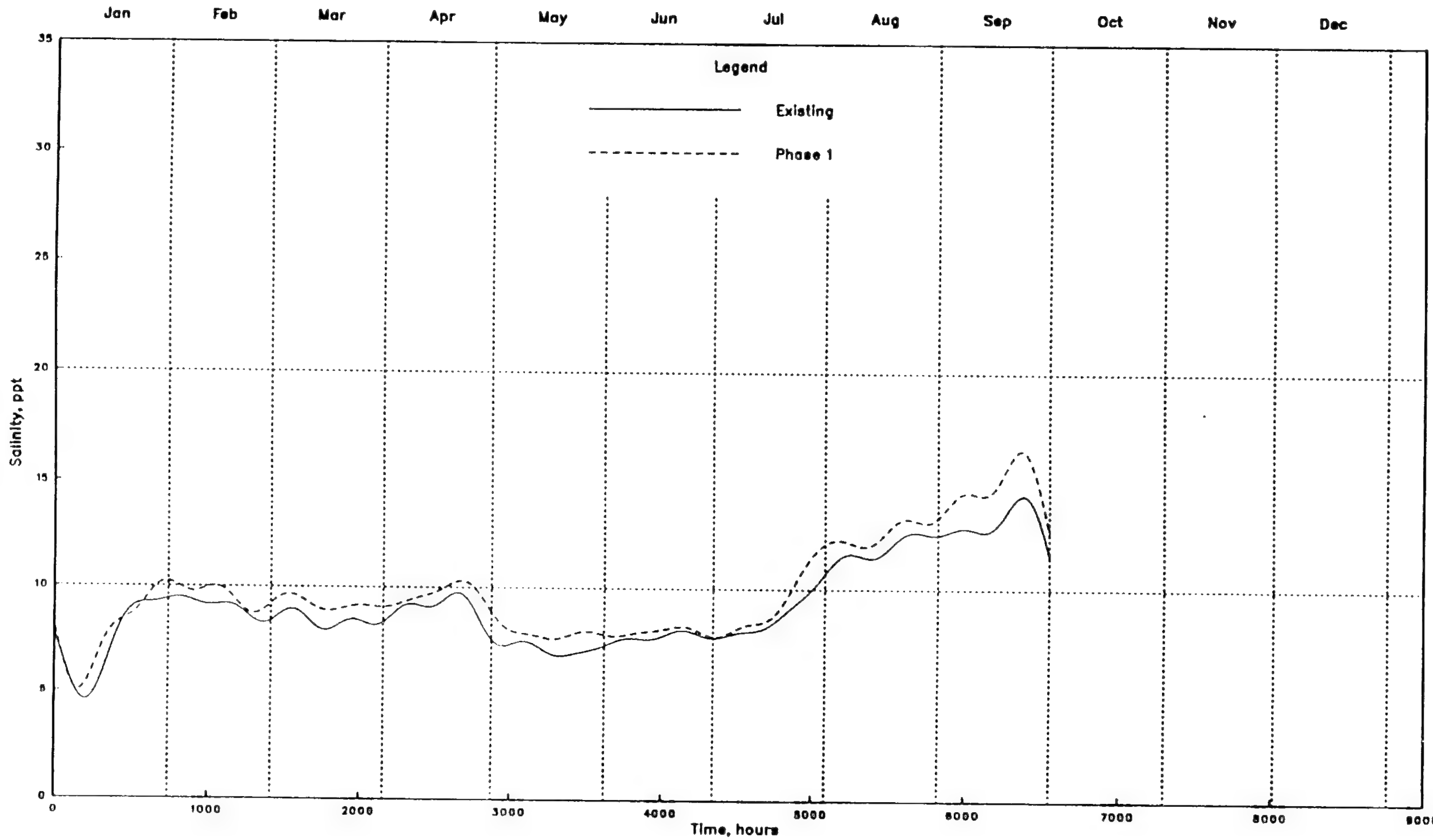
Plate 60

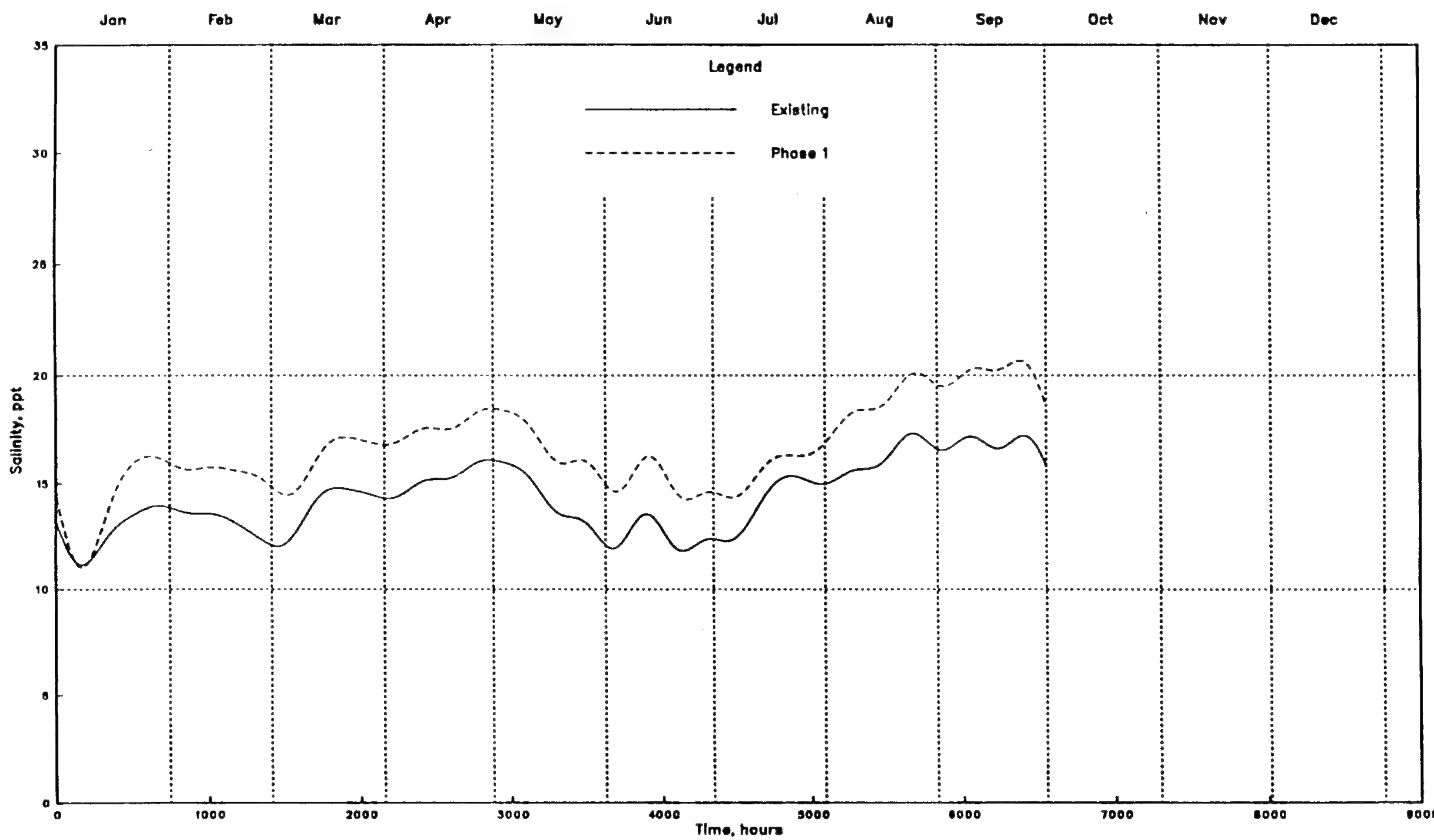


SALINTY TIME SERIES
1999 LOW FLOW
POINT 13

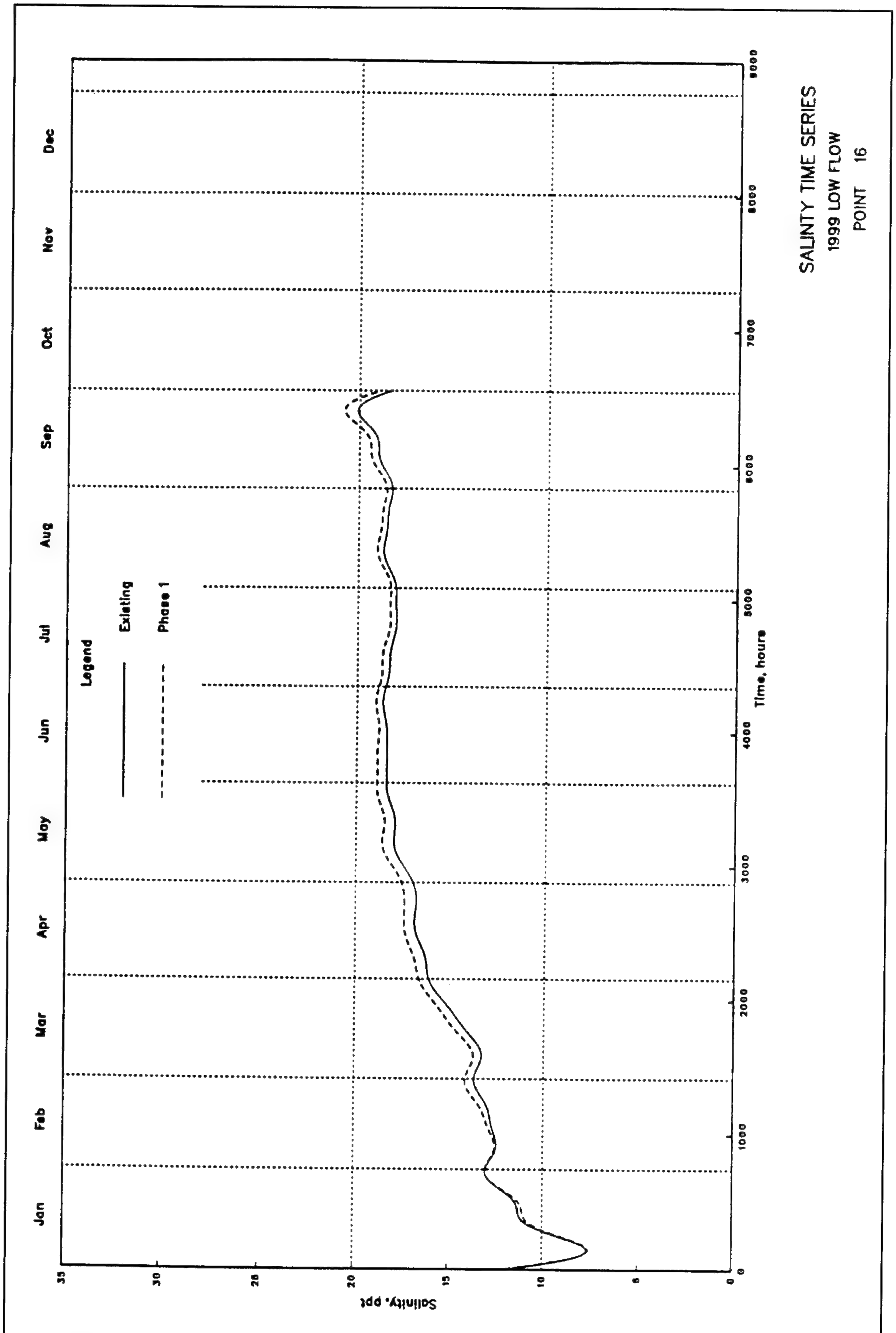


SALINTY TIME SERIES
1999 LOW FLOW
POINT 14

Plate 62



SALINTY TIME SERIES
1999 LOW FLOW
POINT 15



SALINTY TIME SERIES
1999 LOW FLOW
POINT 16
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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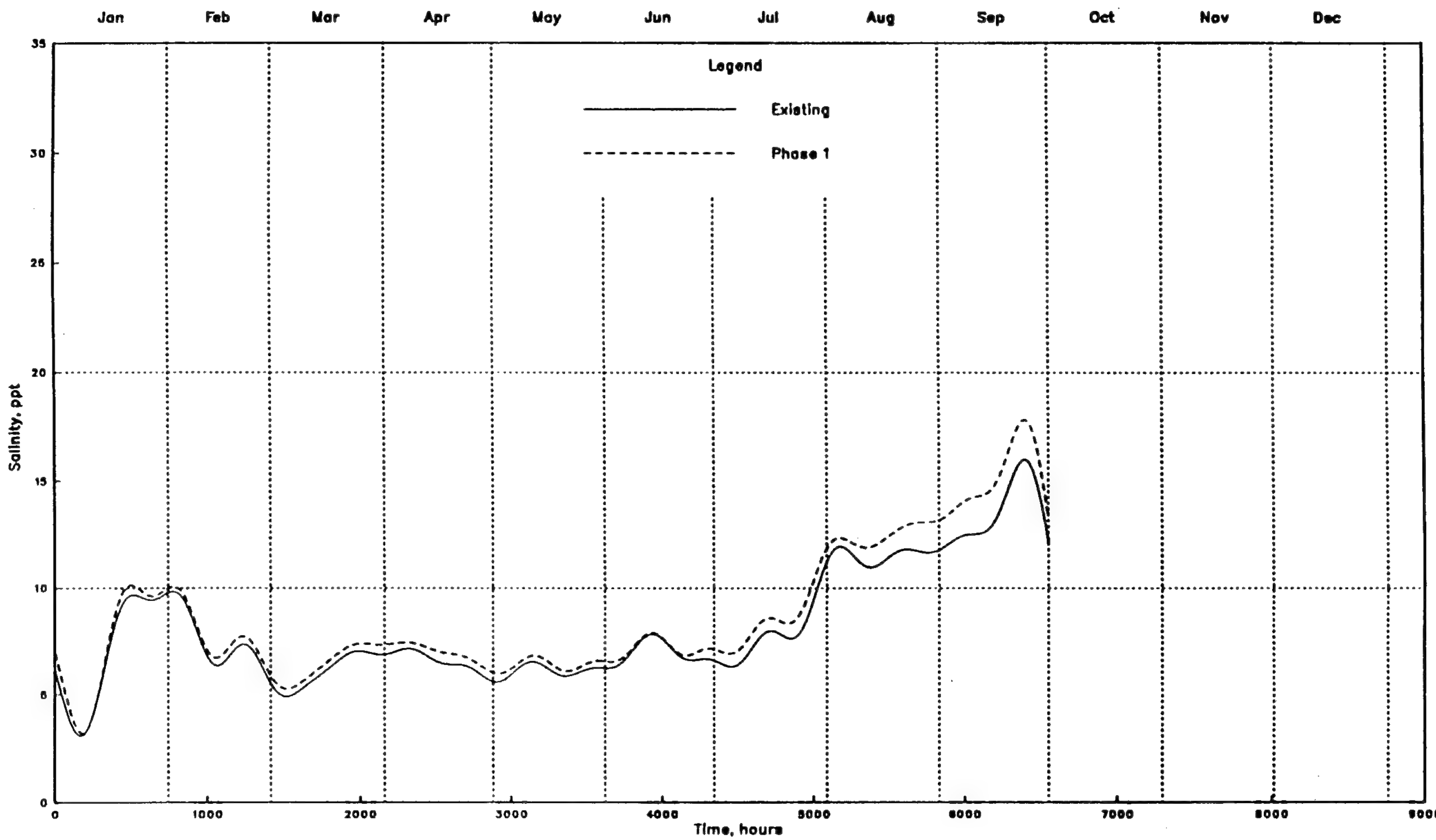
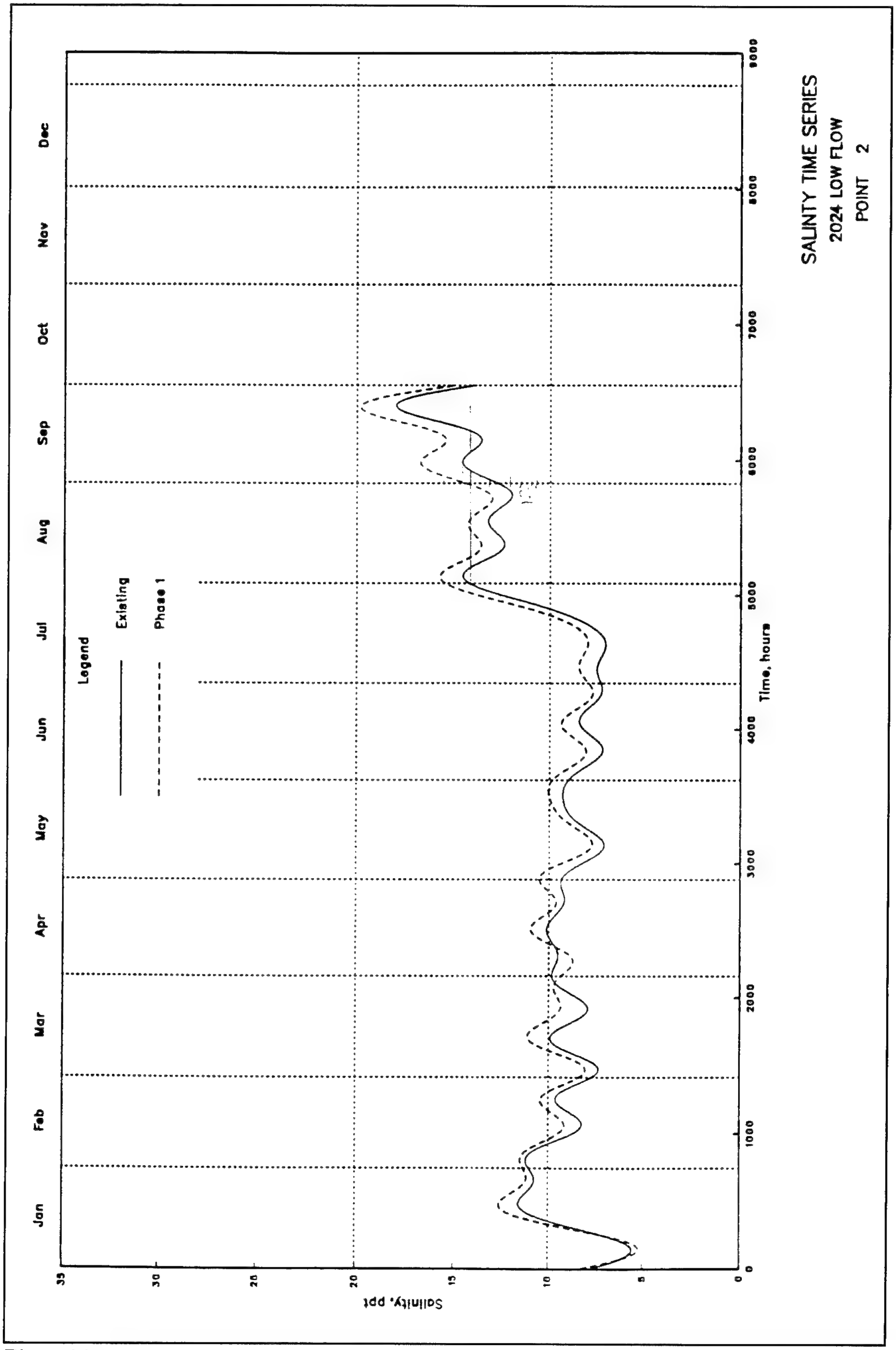
Plate 64



SALINTY TIME SERIES
2024 LOW FLOW
POINT 1

Plate 65


SALINTY TIME SERIES
2024 LOW FLOW
POINT 2
Legend
Existing
Phase 1
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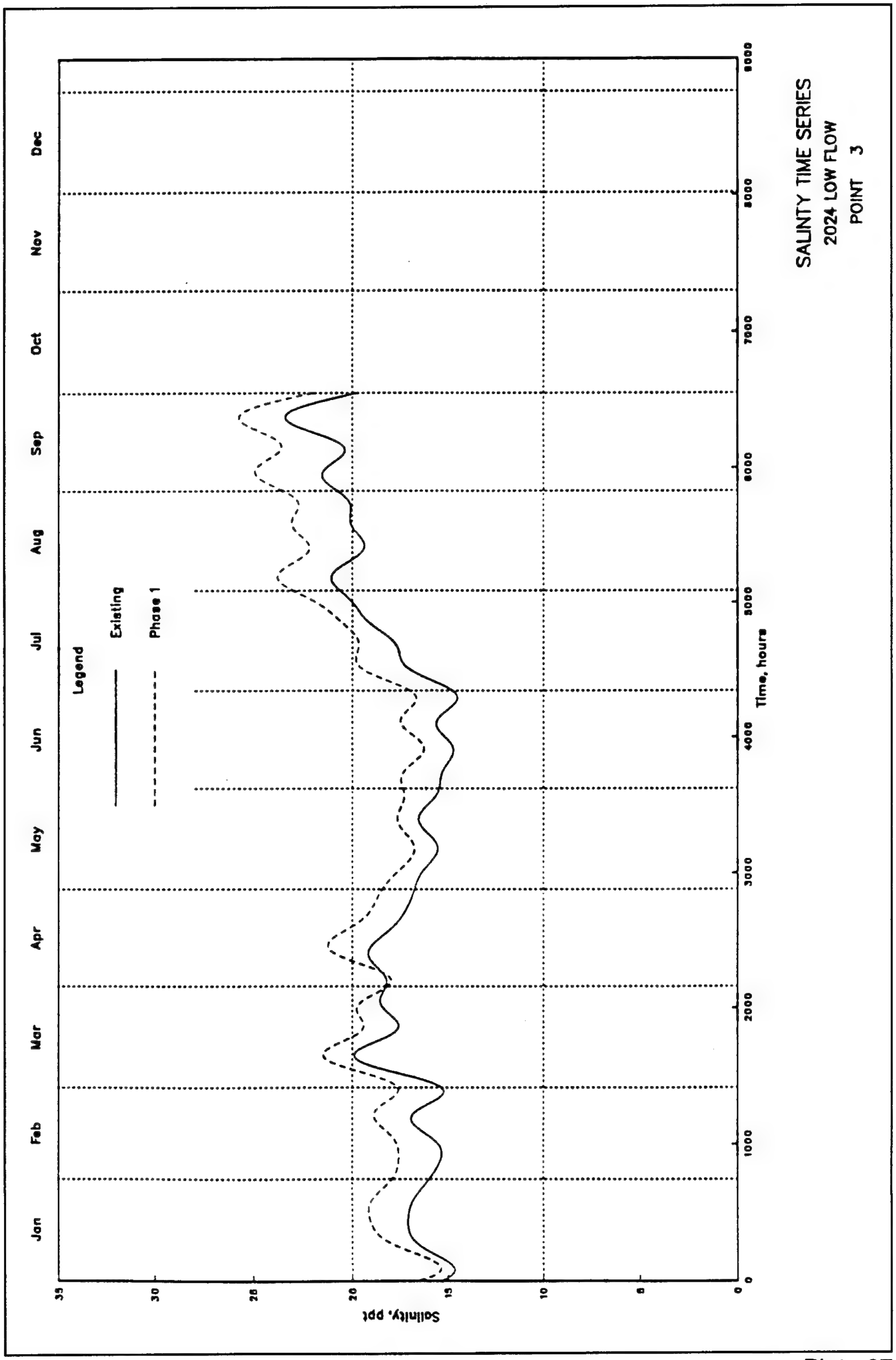
SALINTY TIME SERIES
2024 LOW FLOW
POINT 3
Legend
Existing
Phase 1
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Salinity, ppt
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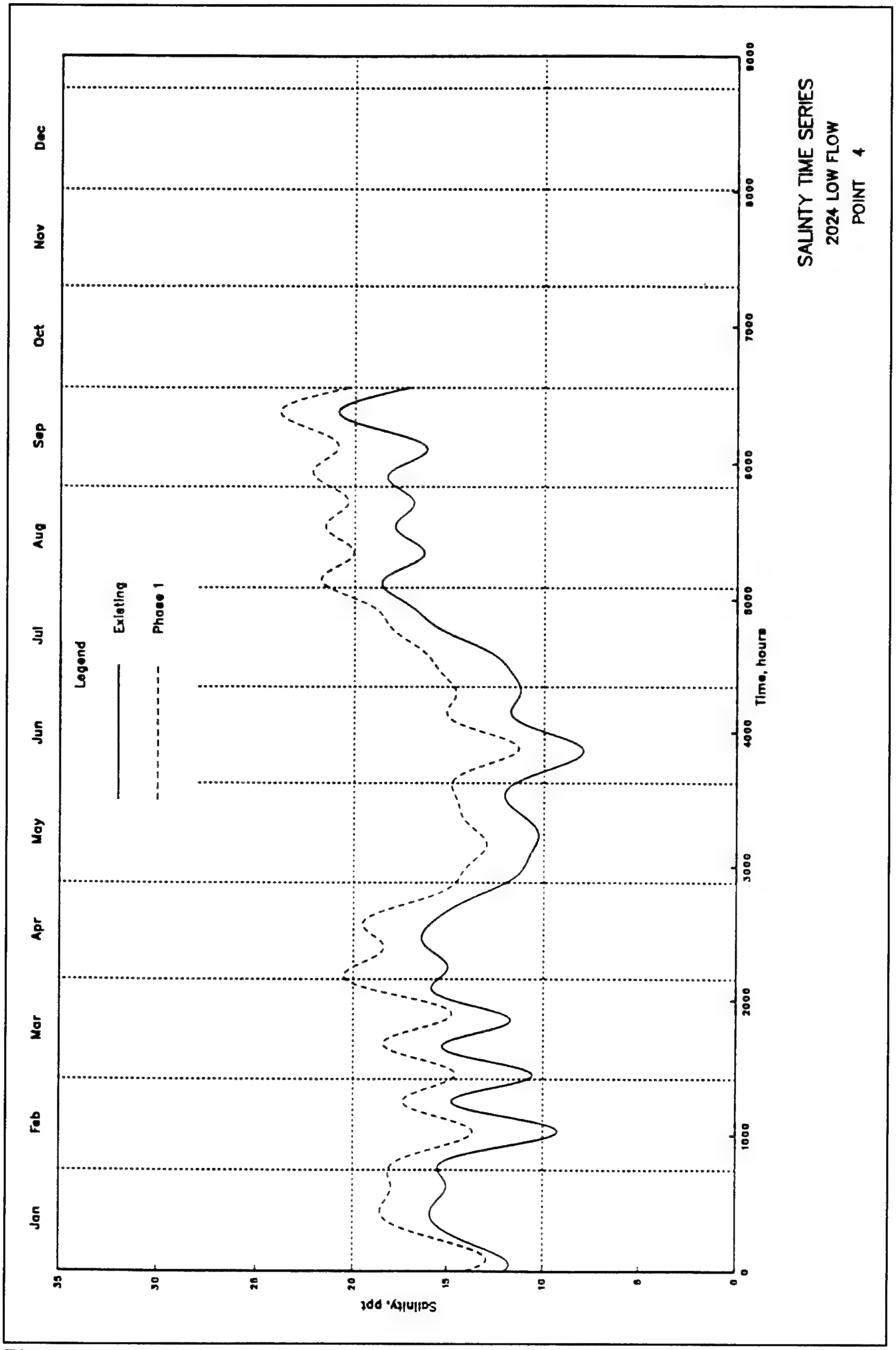
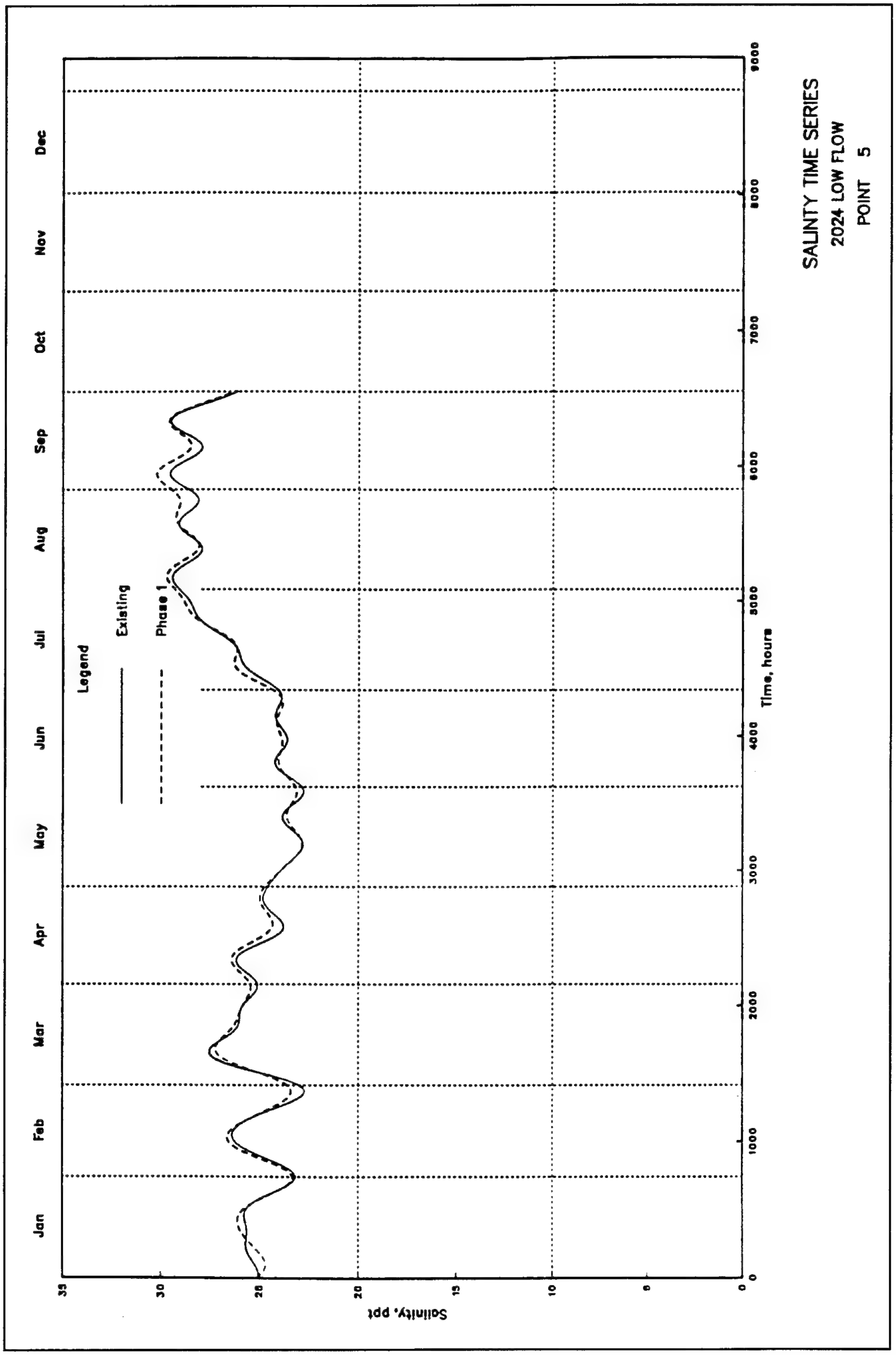
Plate 67



SALINTY TIME SERIES
2024 LOW FLOW
POINT 4

Plate 68


SALINTY TIME SERIES
2024 LOW FLOW
POINT 5
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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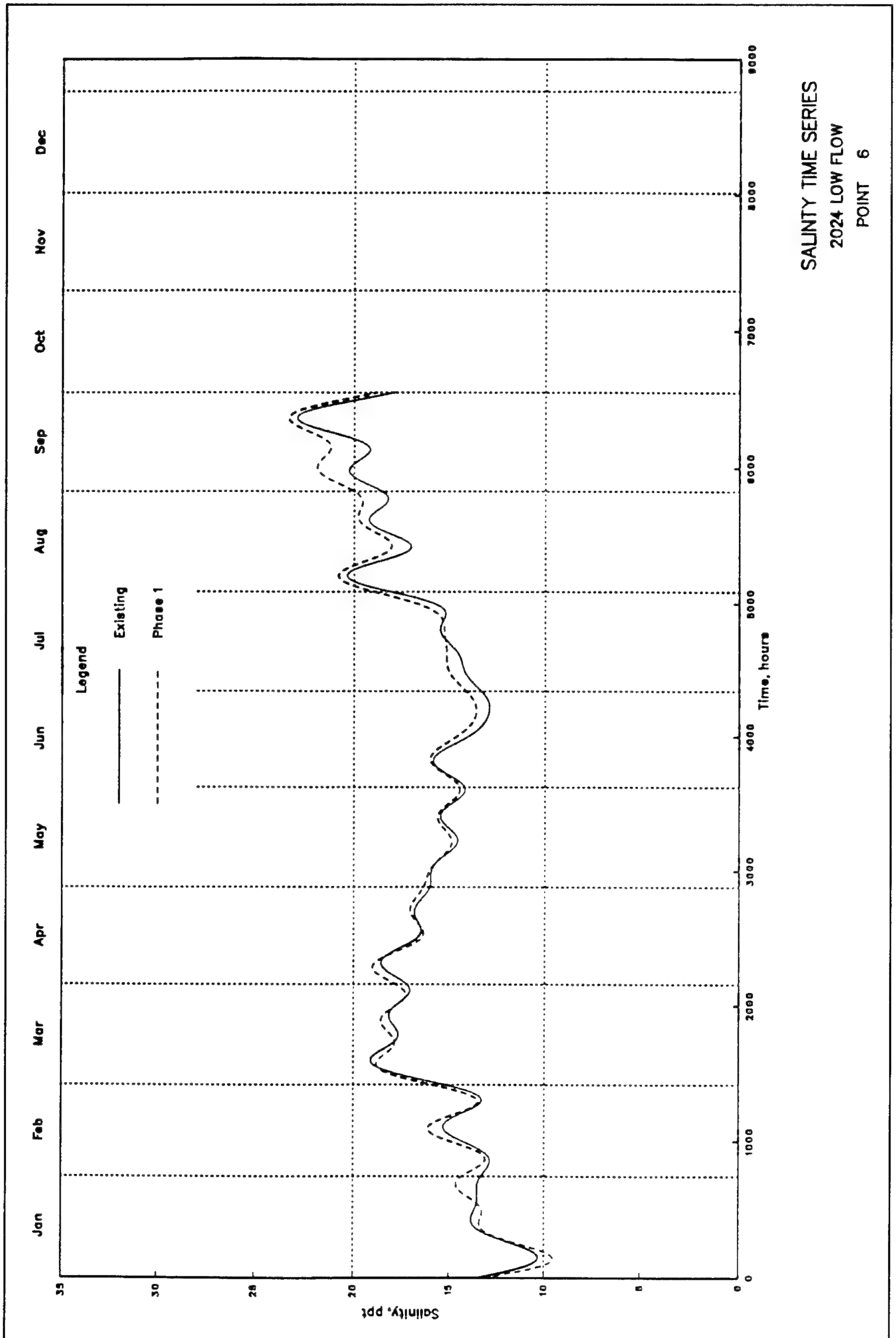
SALINTY TIME SERIES
2024 LOW FLOW
POINT 6
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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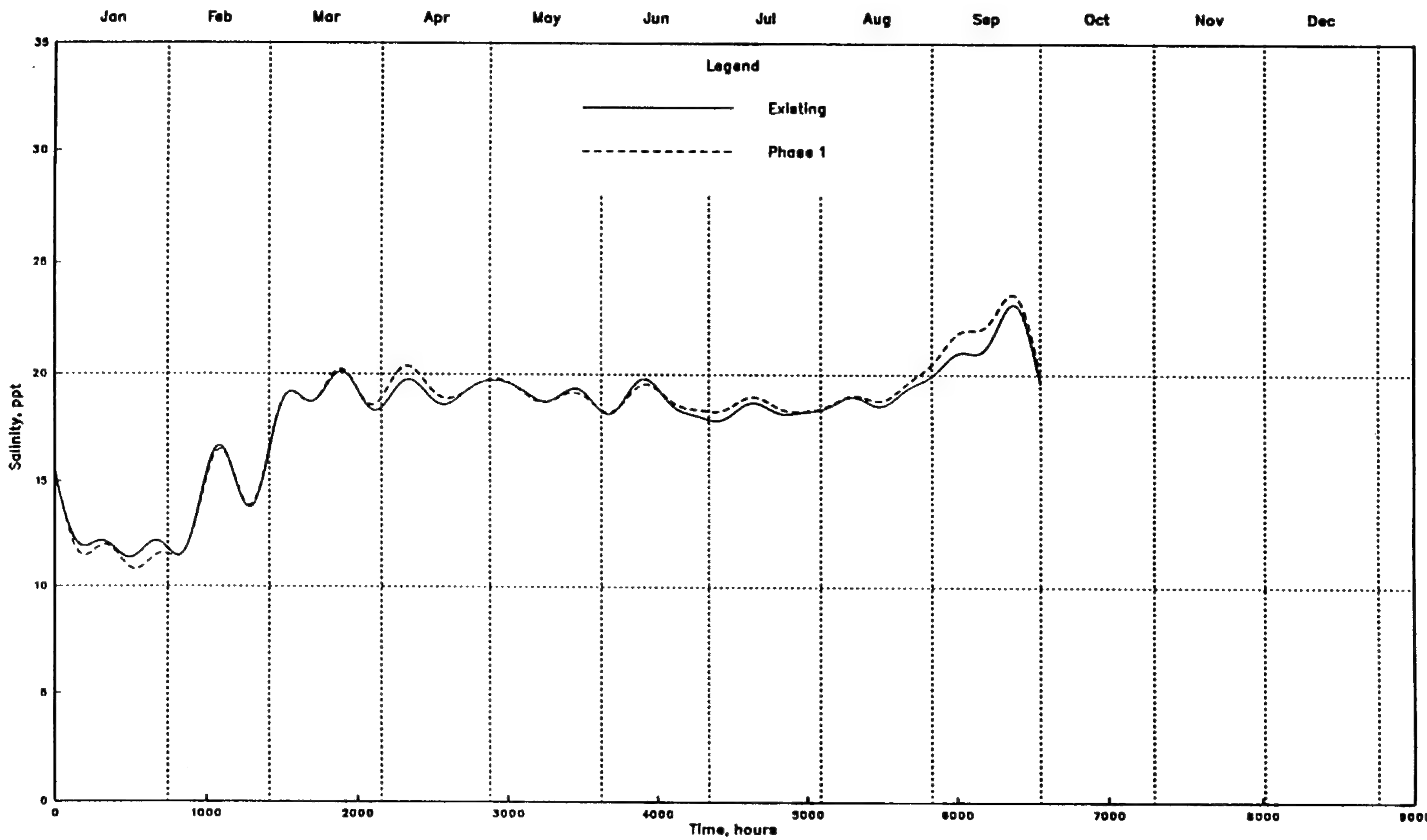
Plate 70



SALINTY TIME SERIES
2024 LOW FLOW
POINT 7

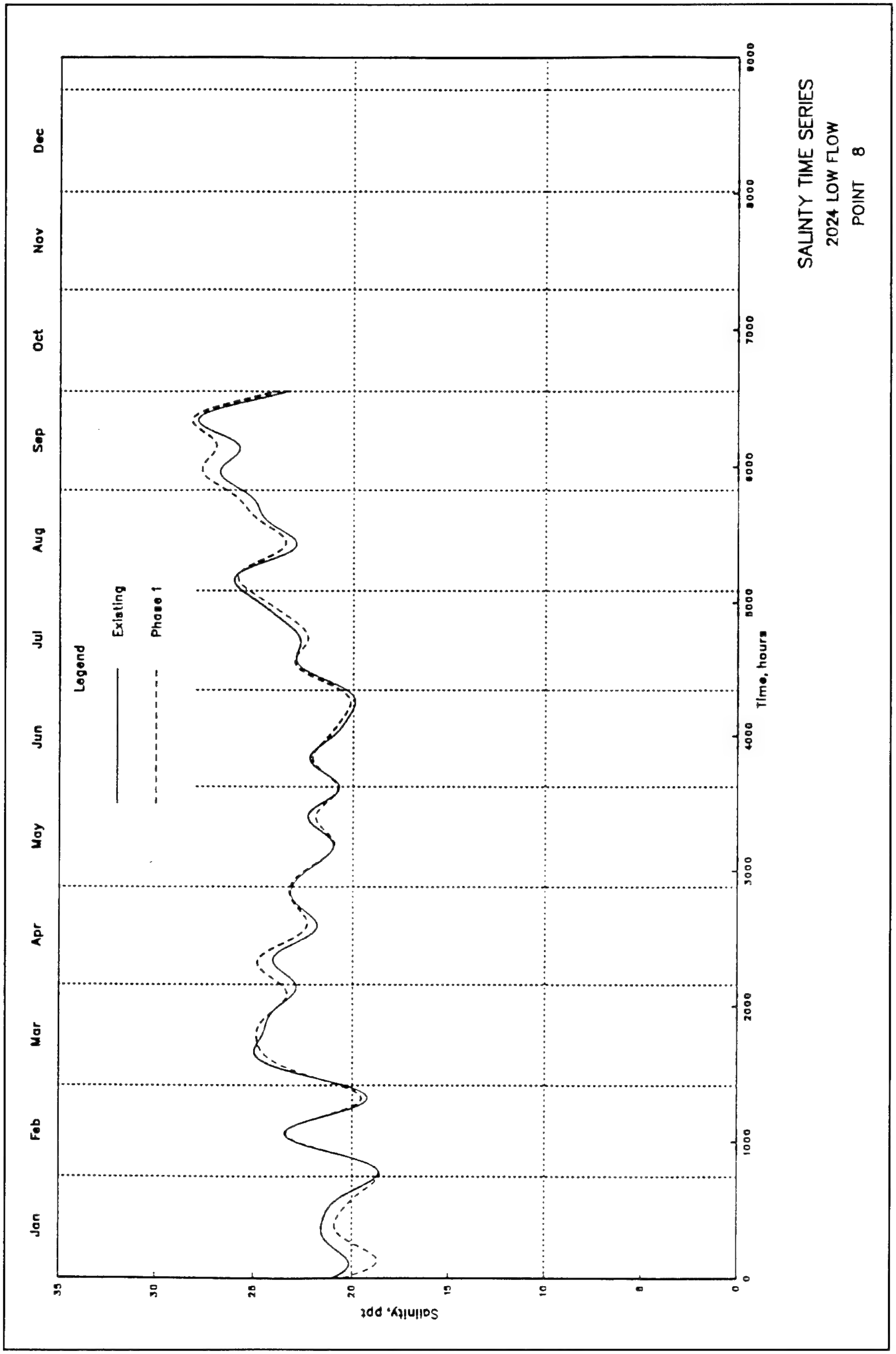

SALINTY TIME SERIES
2024 LOW FLOW
POINT 8
Legend
Existing
Phase 1
Time, hours
Salinity, ppt
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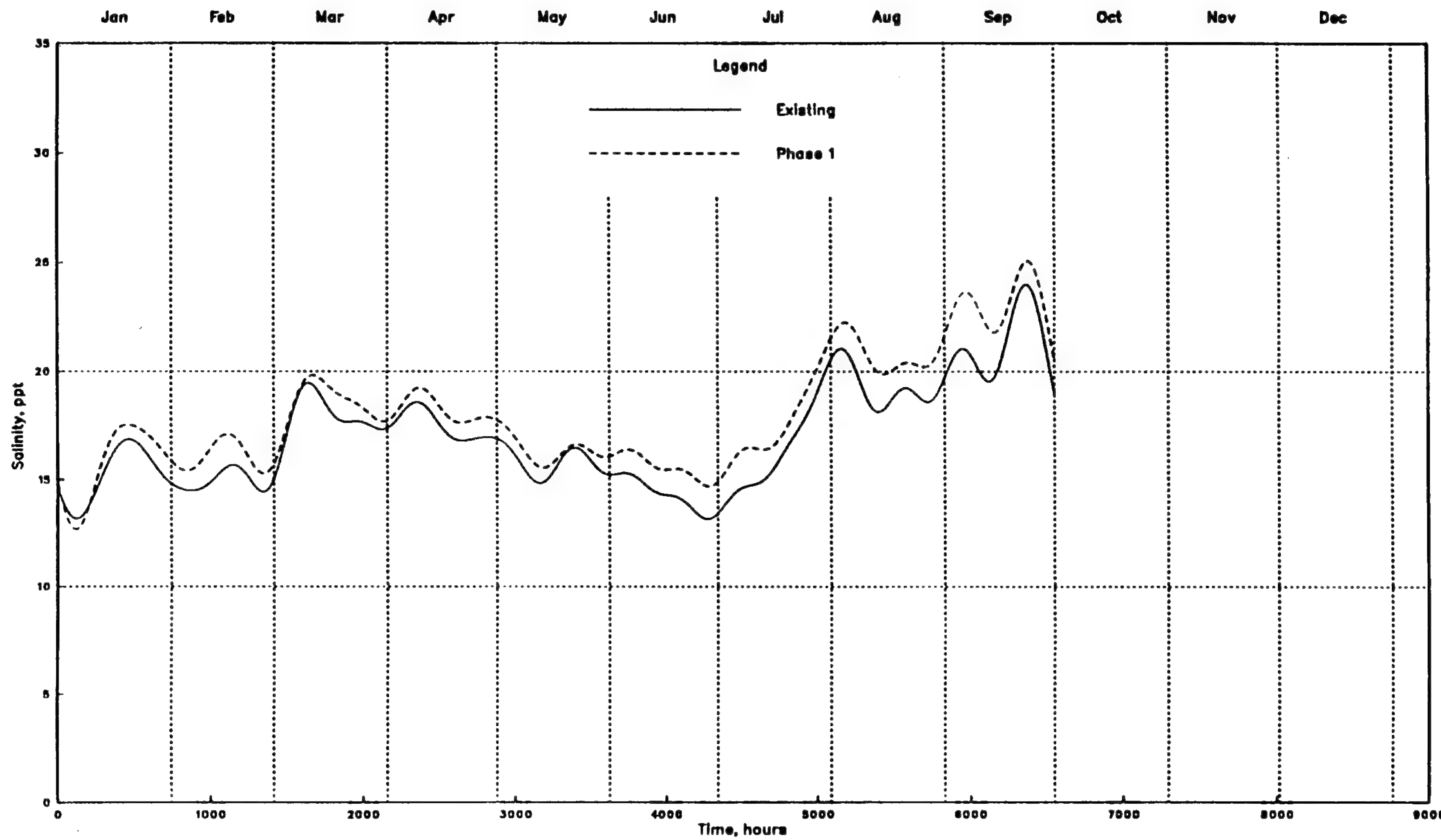
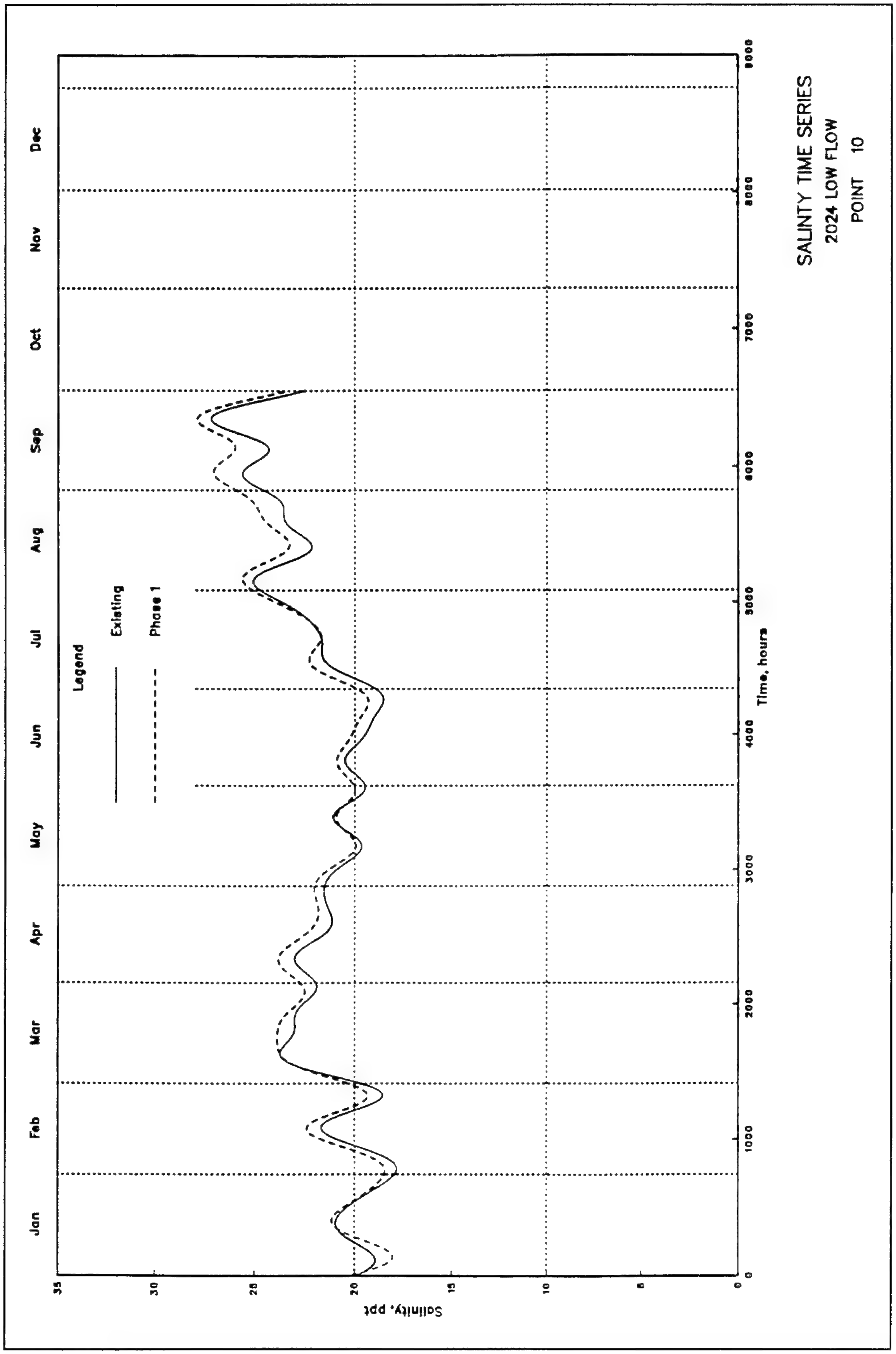
Plate 72



SALINTY TIME SERIES
2024 LOW FLOW
POINT 9

Plate 73



SALINTY TIME SERIES
2024 LOW FLOW
POINT 10
Legend
Existing
Phase 1
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Time, hours
Salinity, ppt
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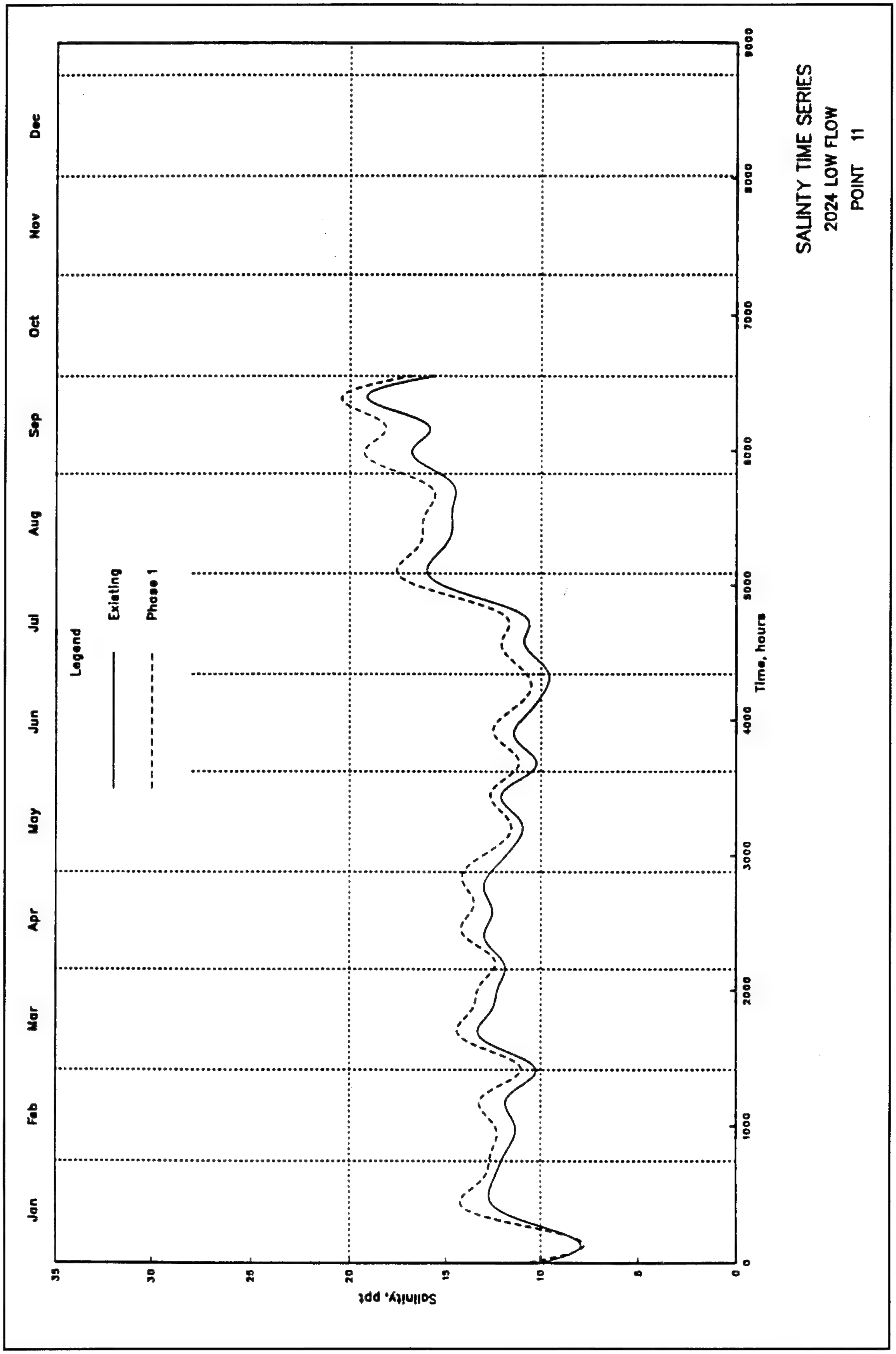
Plate 74


SALINTY TIME SERIES
2024 LOW FLOW
POINT 11
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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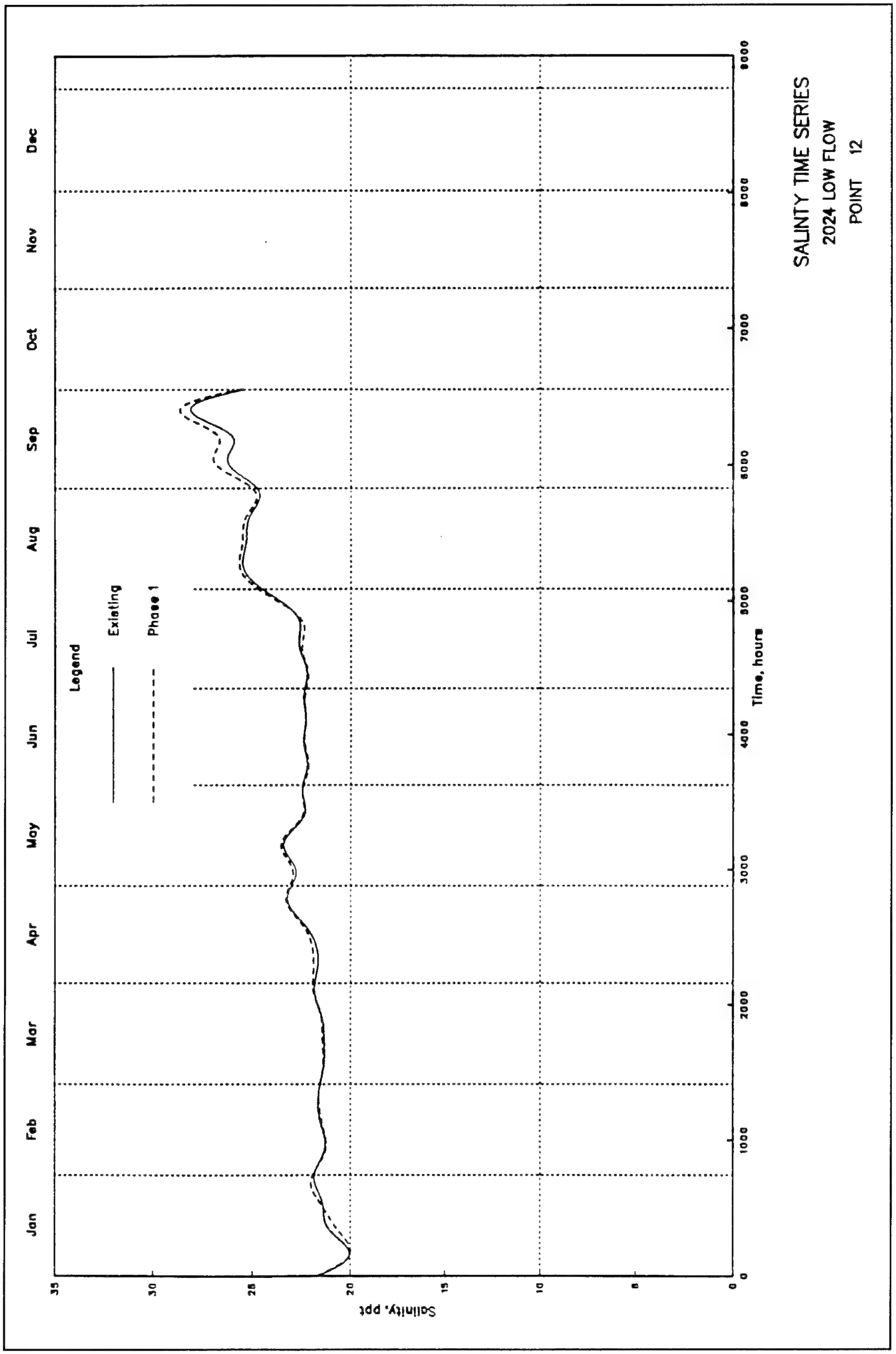

SALINTY TIME SERIES
2024 LOW FLOW
POINT 12
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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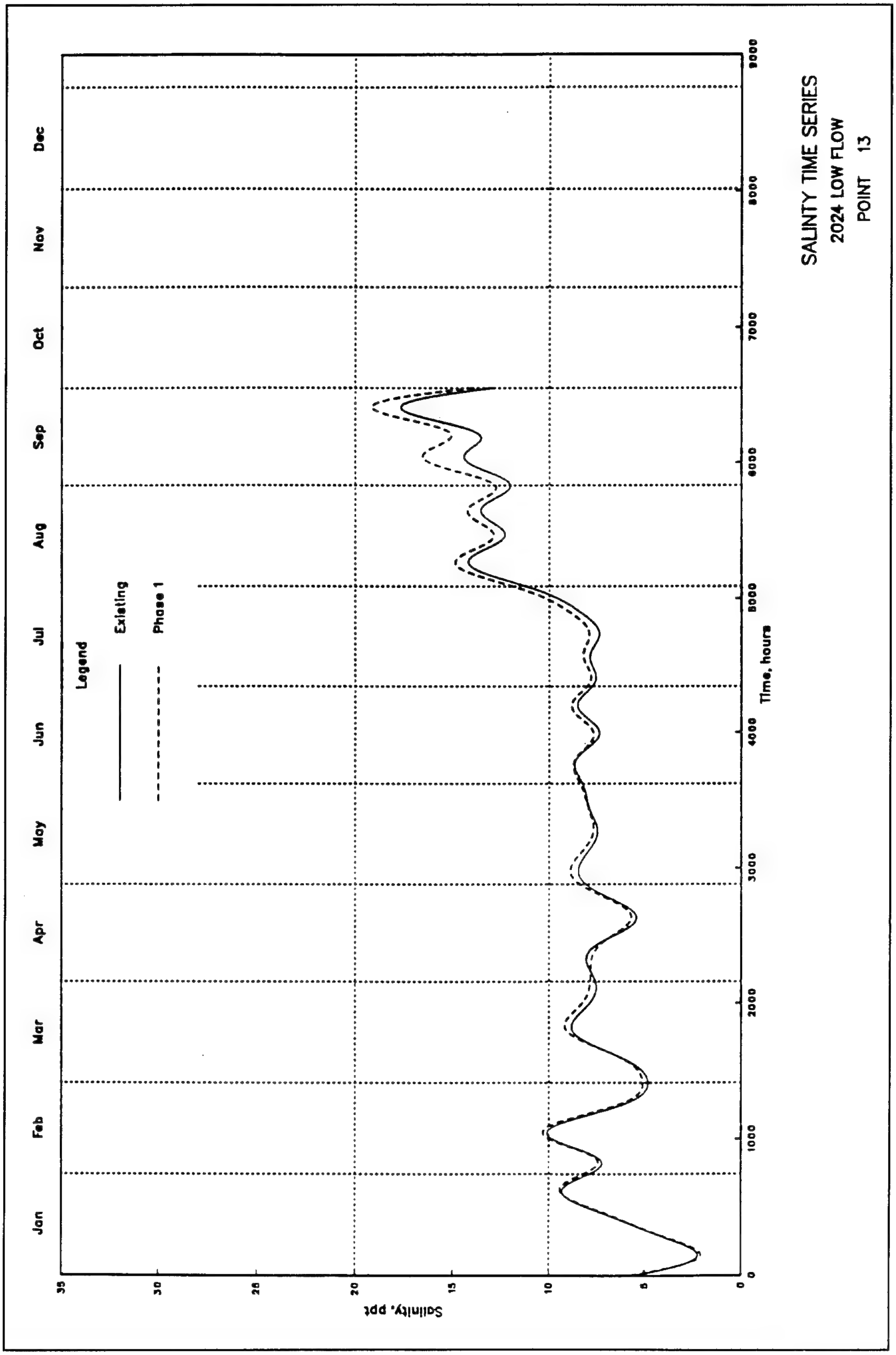
Plate 76


SALINTY TIME SERIES
2024 LOW FLOW
POINT 13
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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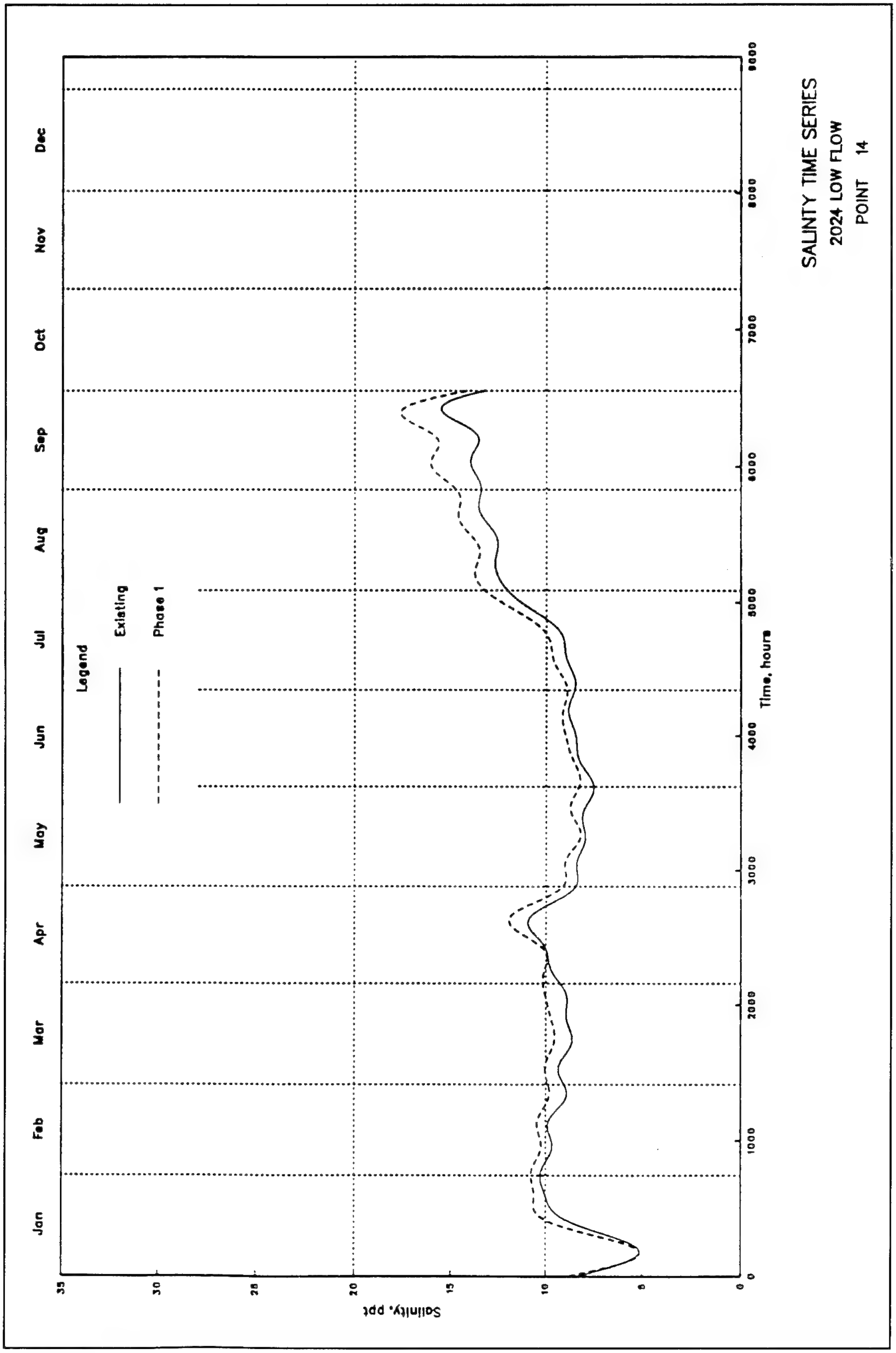
SALINTY TIME SERIES
2024 LOW FLOW
POINT 14
Legend
Existing
Phase 1
Time, hours
Salinity, ppt
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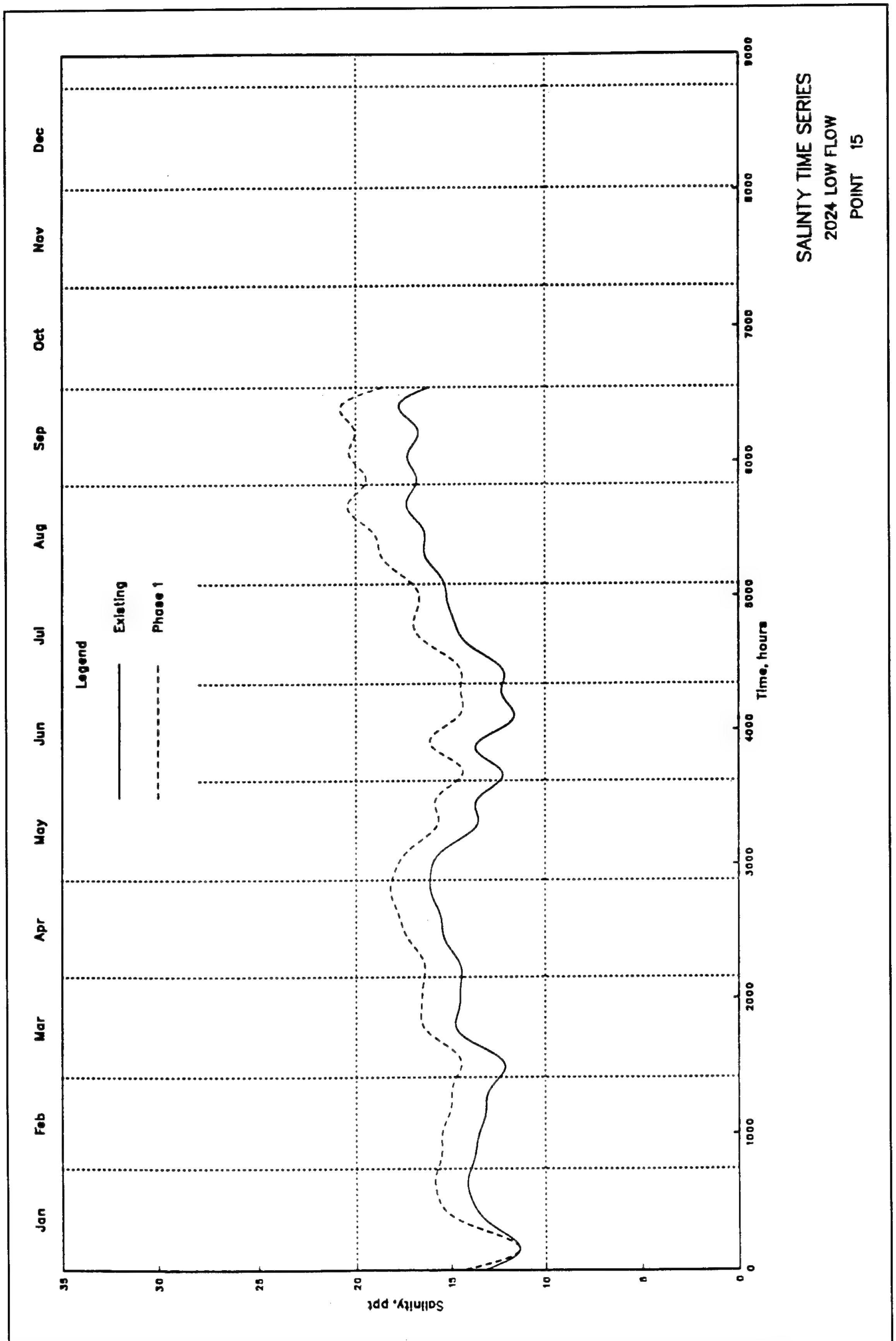
Plate 78



SALINITY TIME SERIES
2024 LOW FLOW
POINT 15
Legend
Existing
Phase 1
Time, hours
Salinity, ppt
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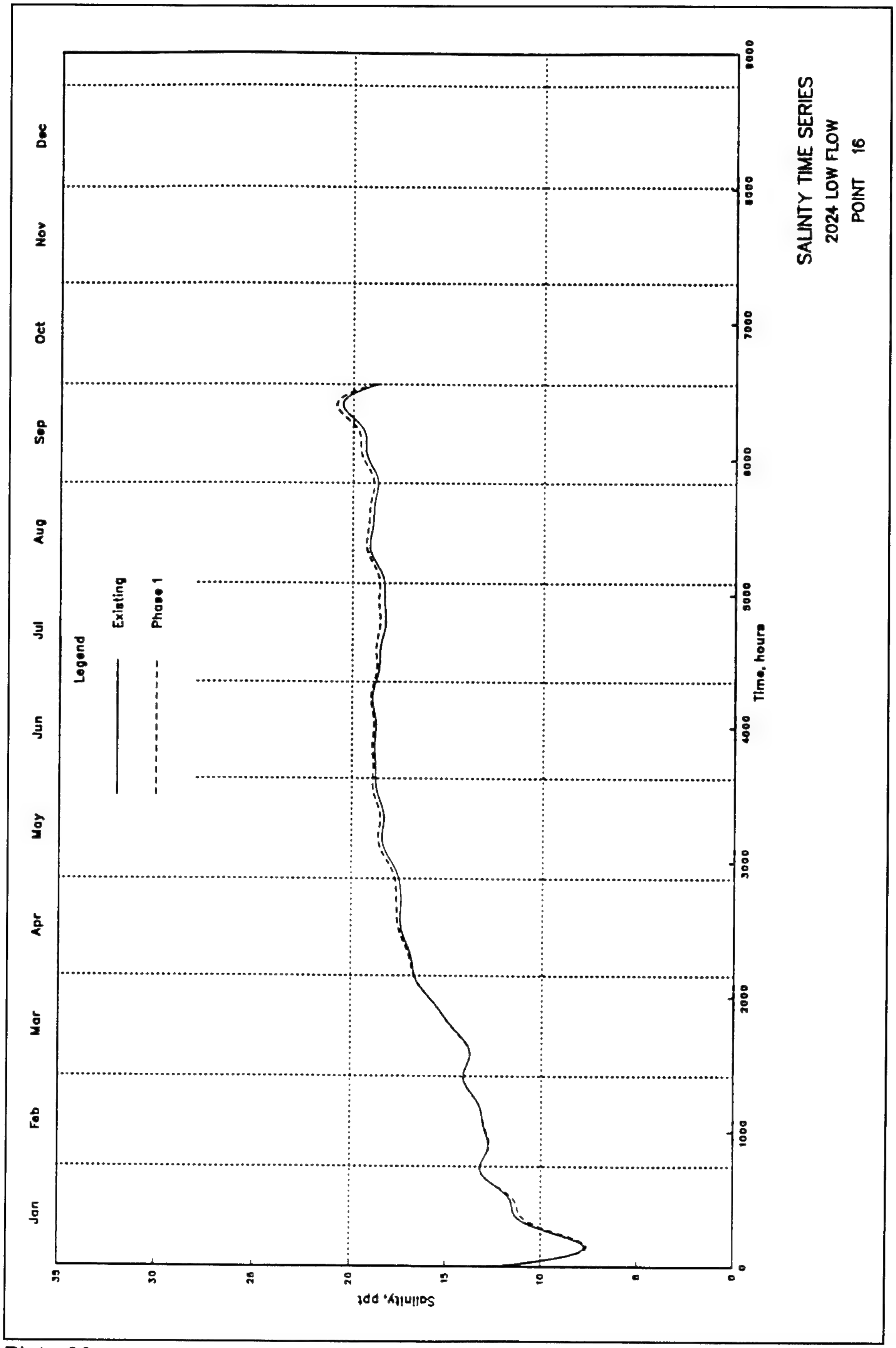

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Legend
Existing
Phase 1
Salinity, ppt
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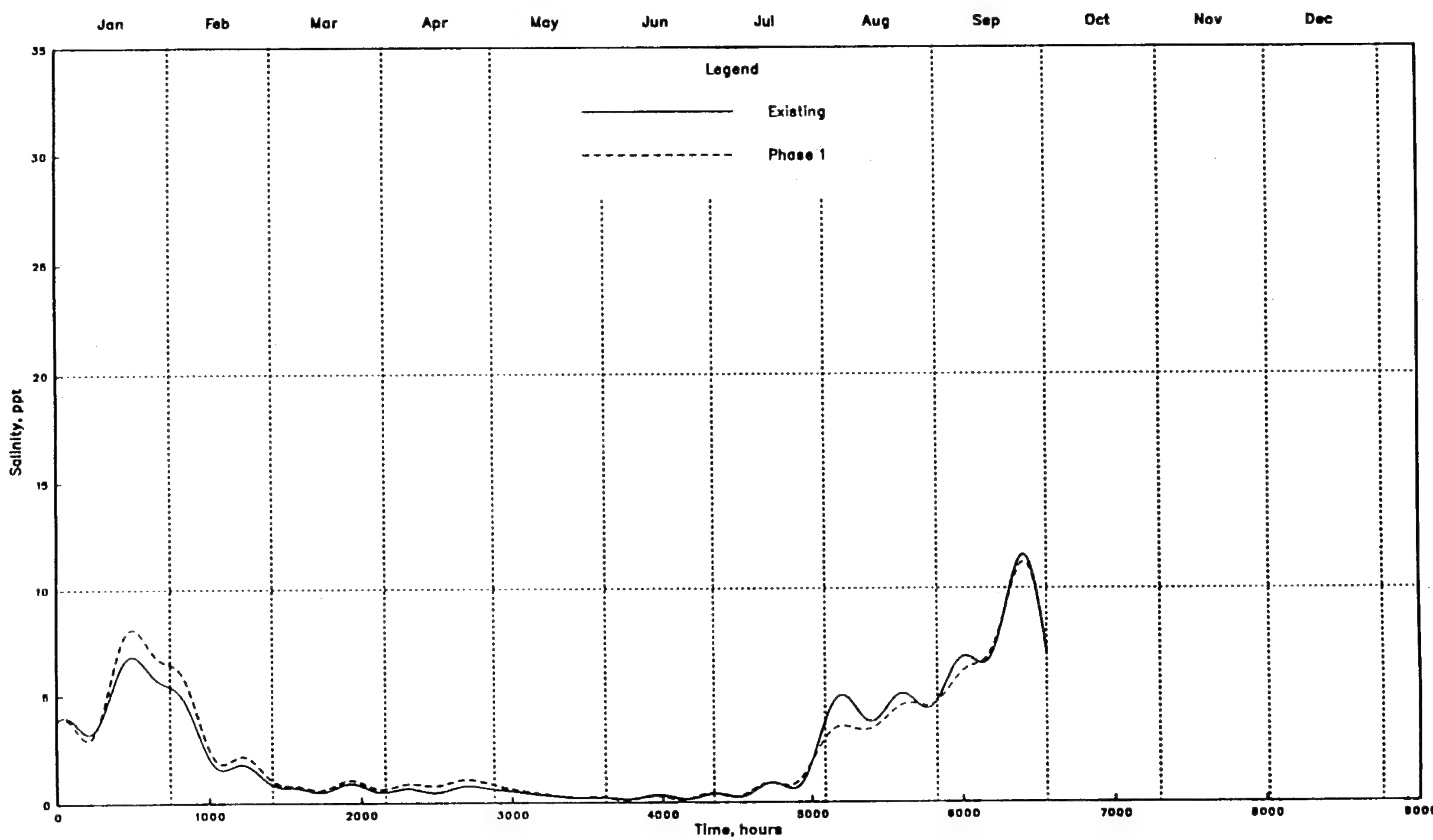
SALINTY TIME SERIES
2024 LOW FLOW
POINT 16



SALINTY TIME SERIES
2024 MEDIUM FLOW
POINT 1

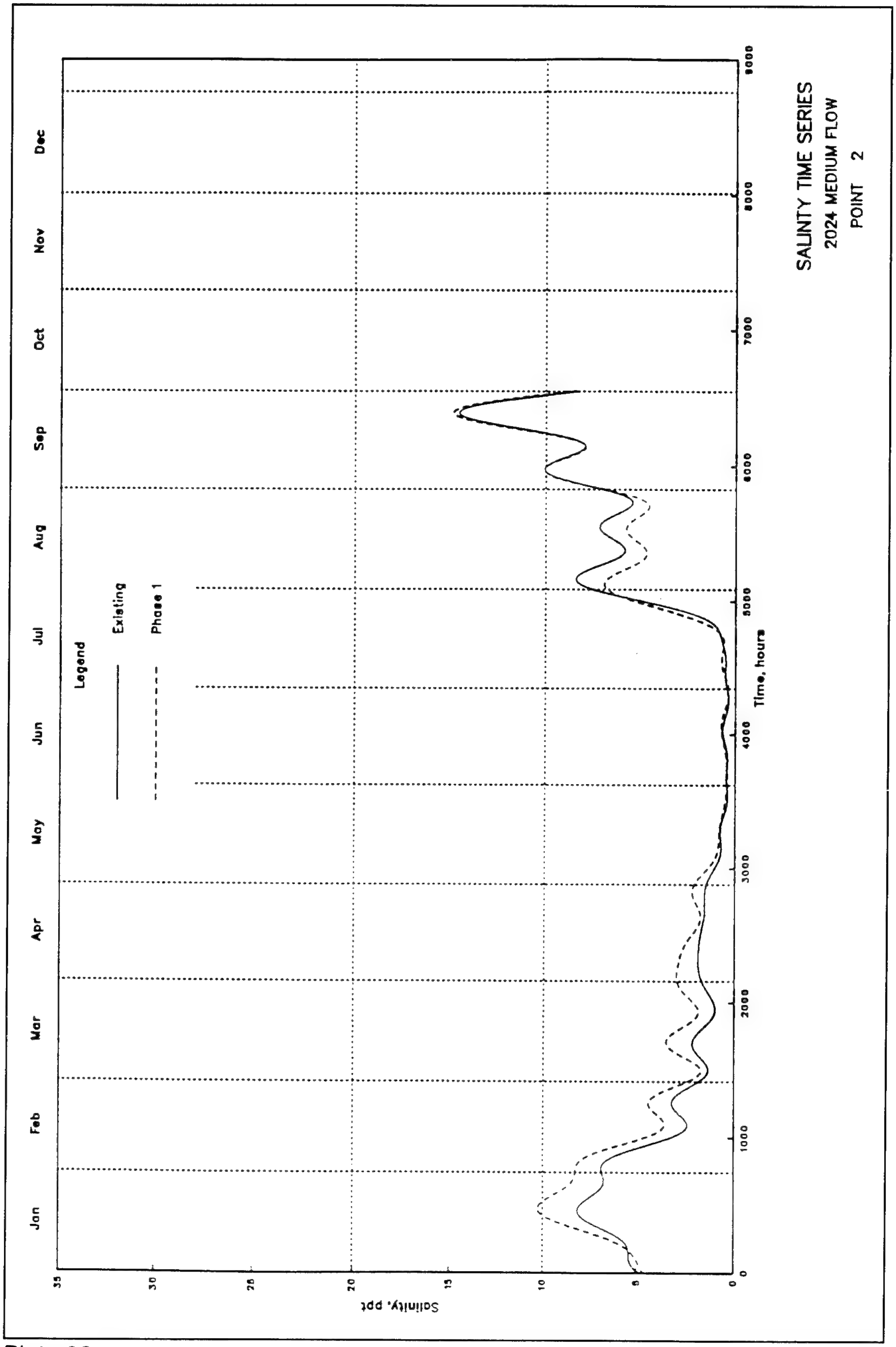

SALINTY TIME SERIES
2024 MEDIUM FLOW
POINT 2
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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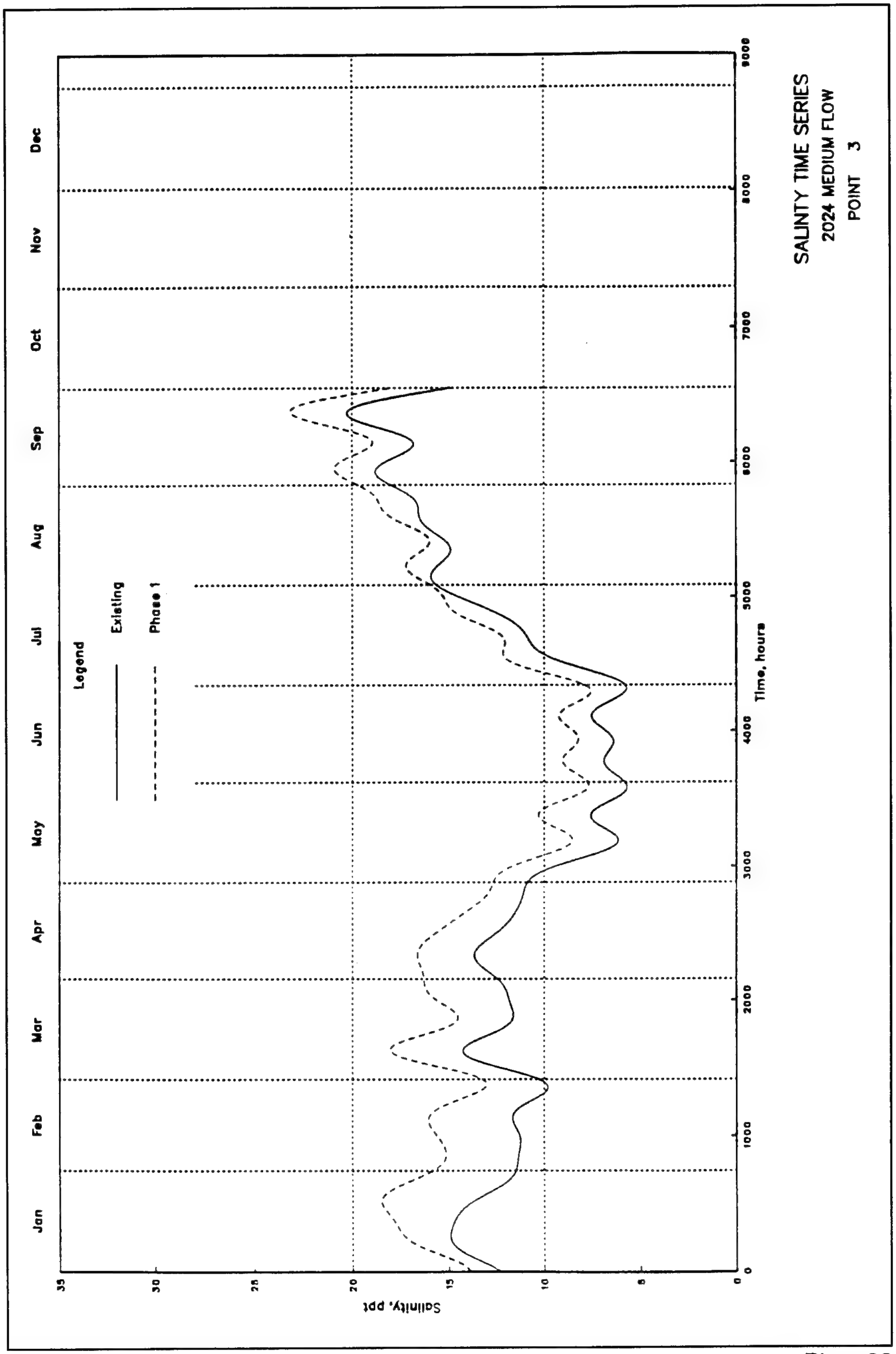
Plate 82



SALINTY TIME SERIES
2024 MEDIUM FLOW
POINT 3
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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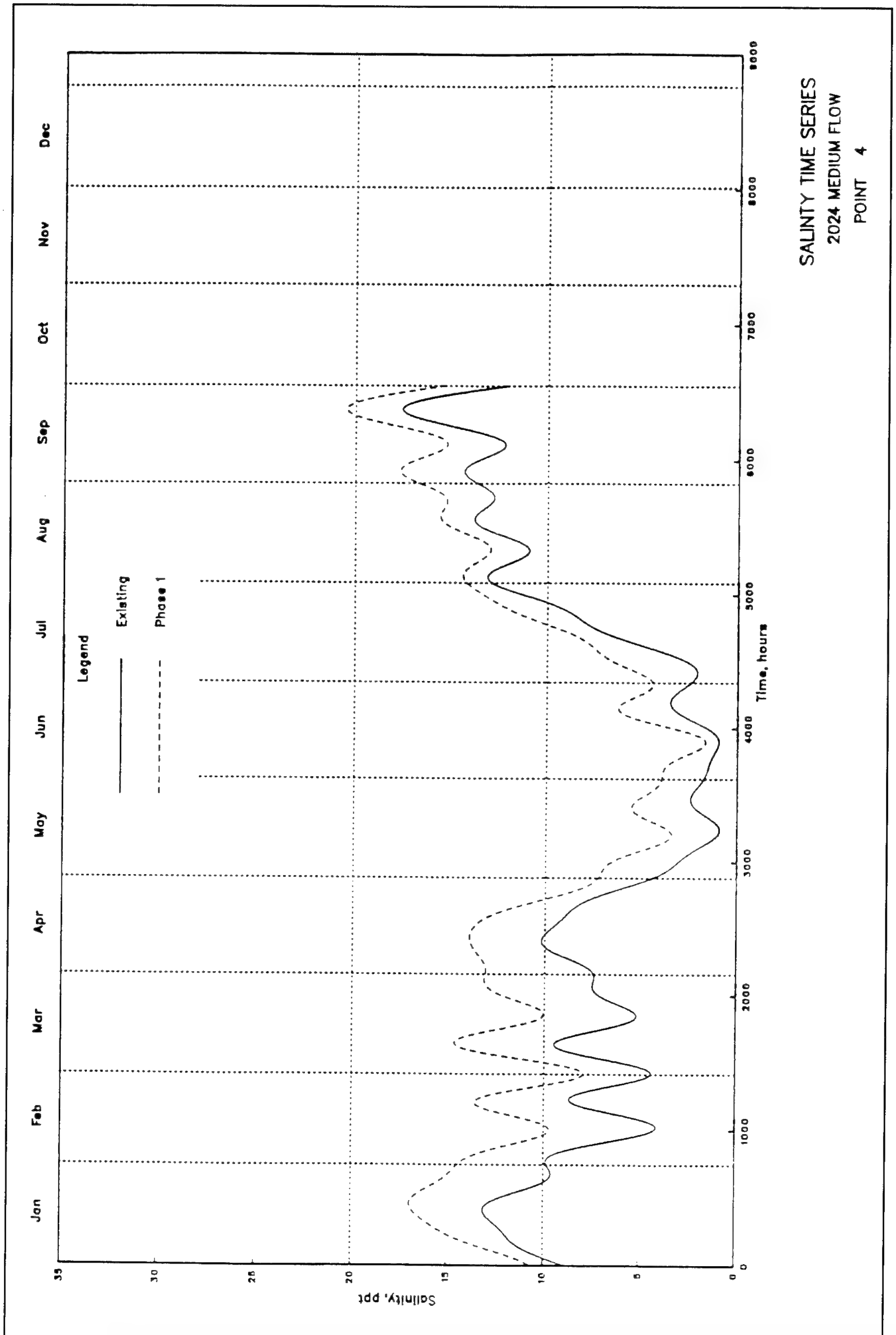
SALINTY TIME SERIES
2024 MEDIUM FLOW
POINT 4
Legend
Existing
Phase 1
Time, hours
Salinity, ppt
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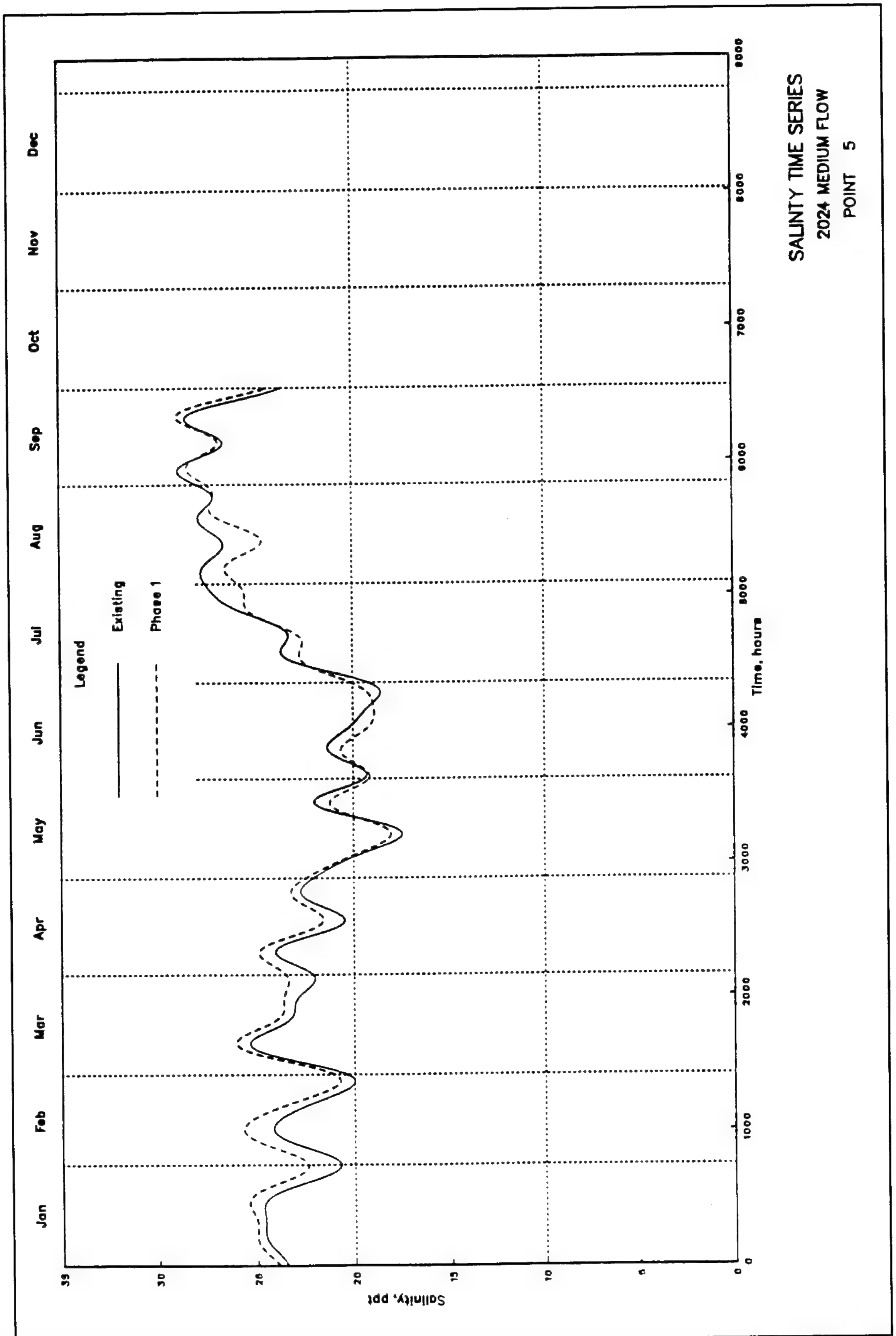
Plate 84


SALINTY TIME SERIES
2024 MEDIUM FLOW
POINT 5
Legend
Existing
Phase 1
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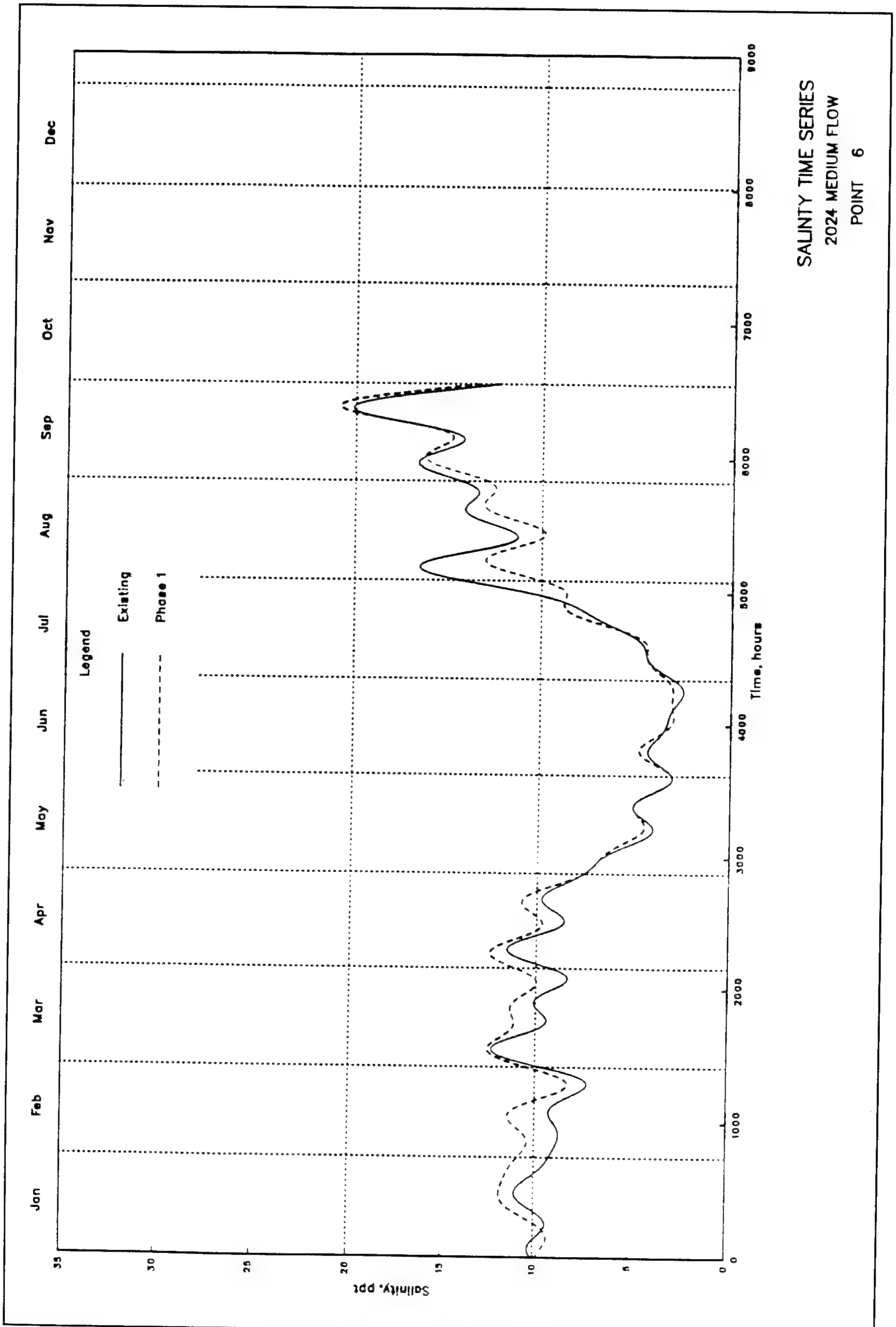
Time, hours
Salinity, ppt


SALINTY TIME SERIES
2024 MEDIUM FLOW
POINT 6
Legend
Existing
Phase 1
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Time, hours
Salinity, ppt
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Plate 86

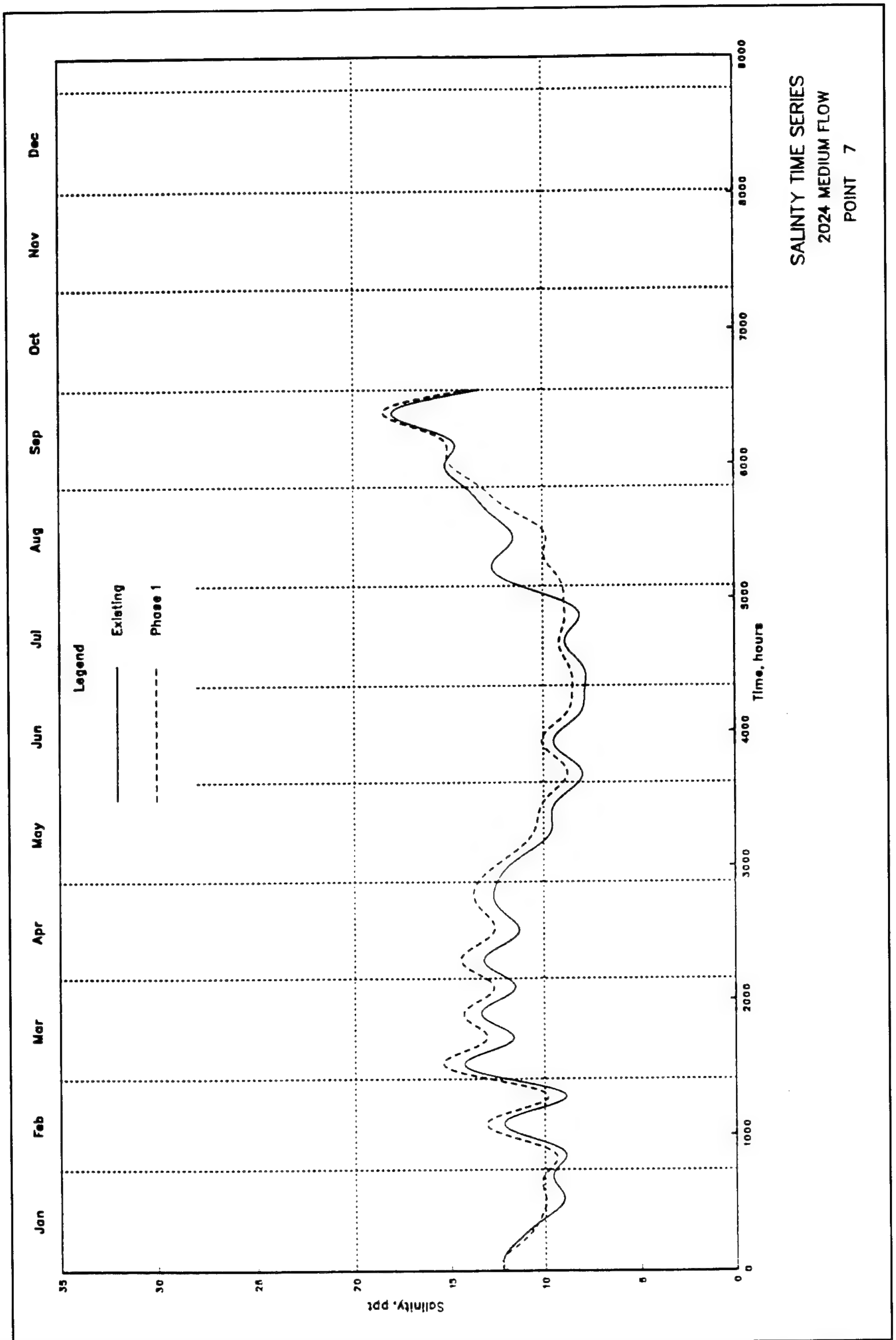
SALINTY TIME SERIES
2024 MEDIUM FLOW
POINT 7
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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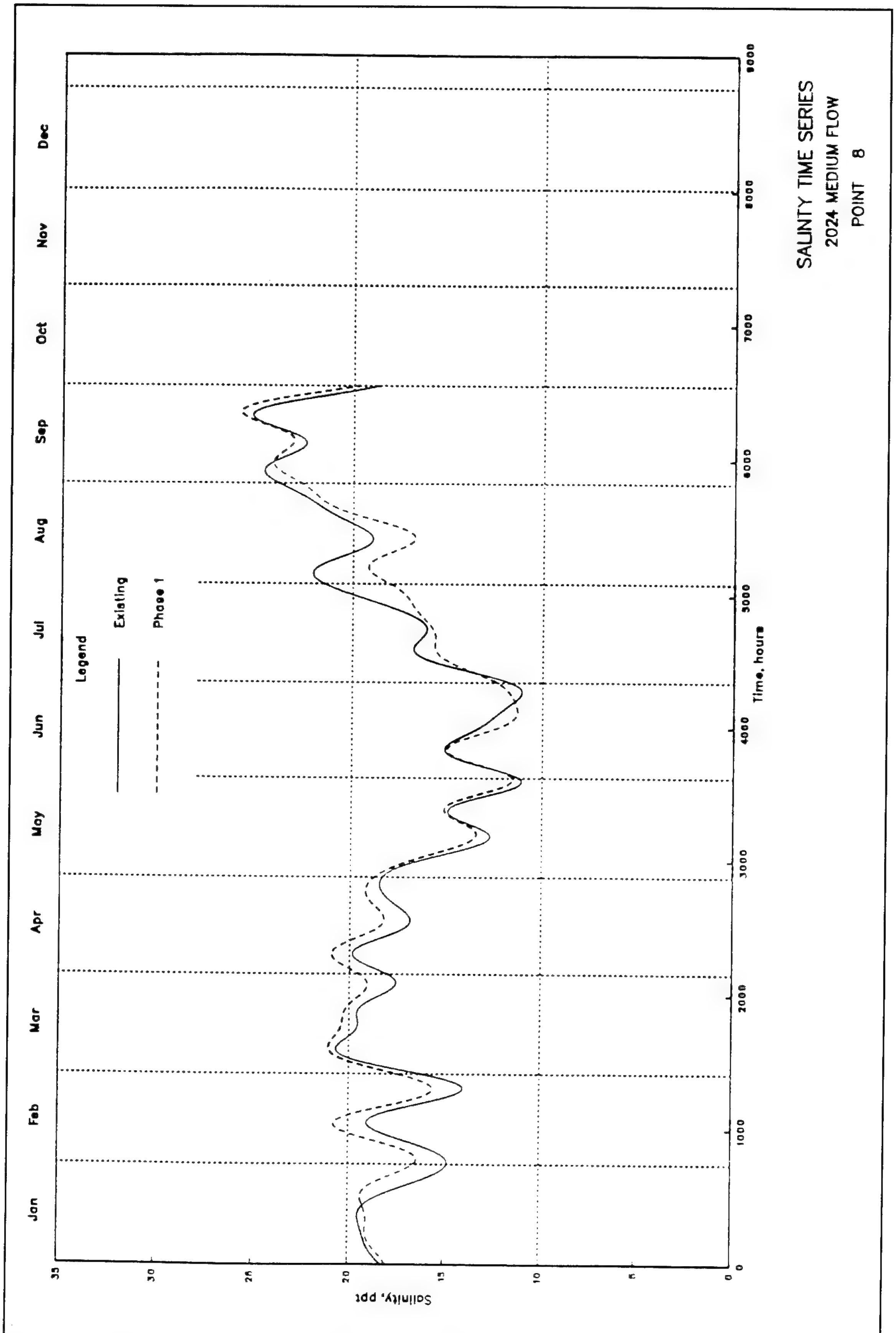
Plate 87



SALINTY TIME SERIES
2024 MEDIUM FLOW
POINT 8
Legend
Existing
Phase 1
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Time, hours
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Salinity, ppt
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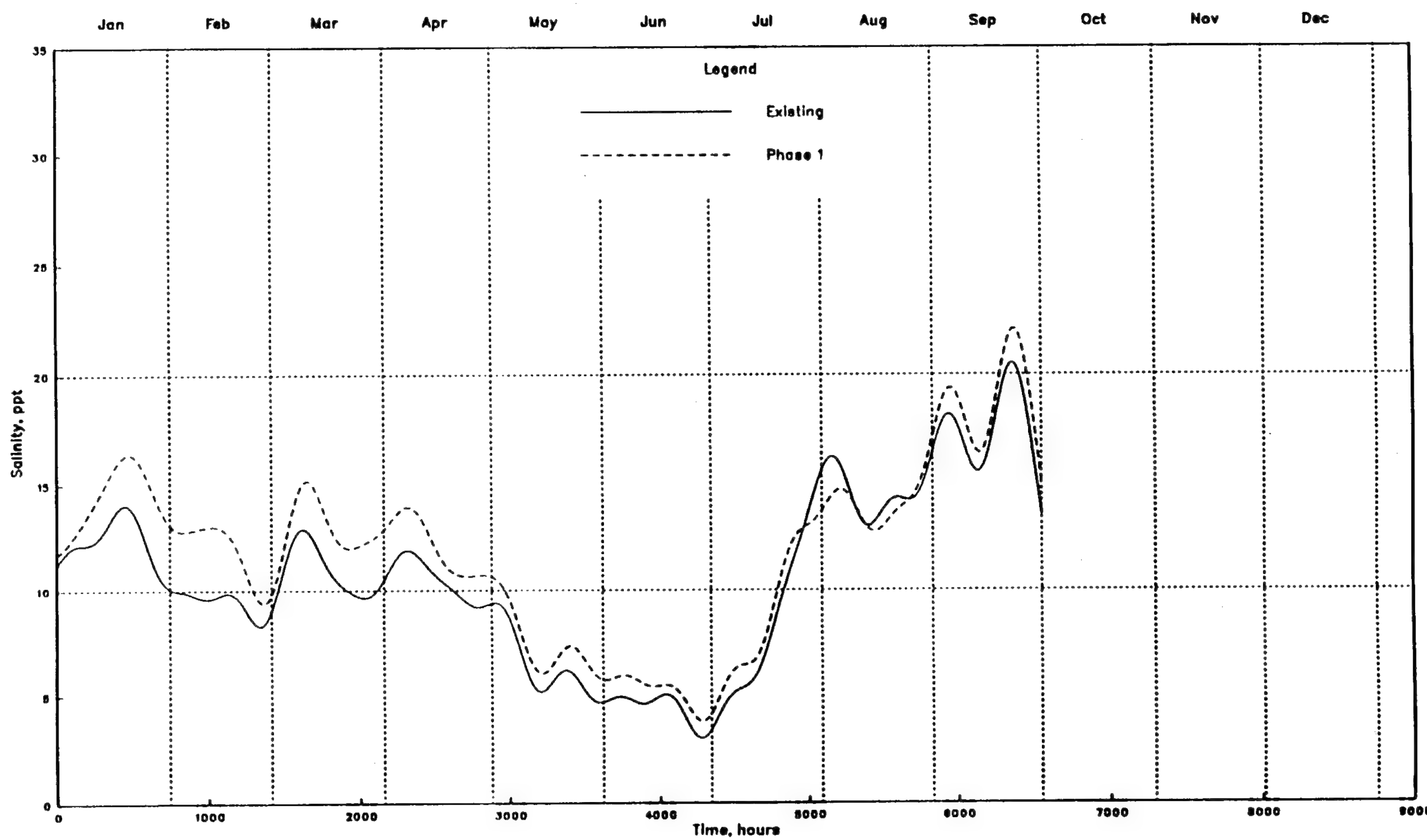
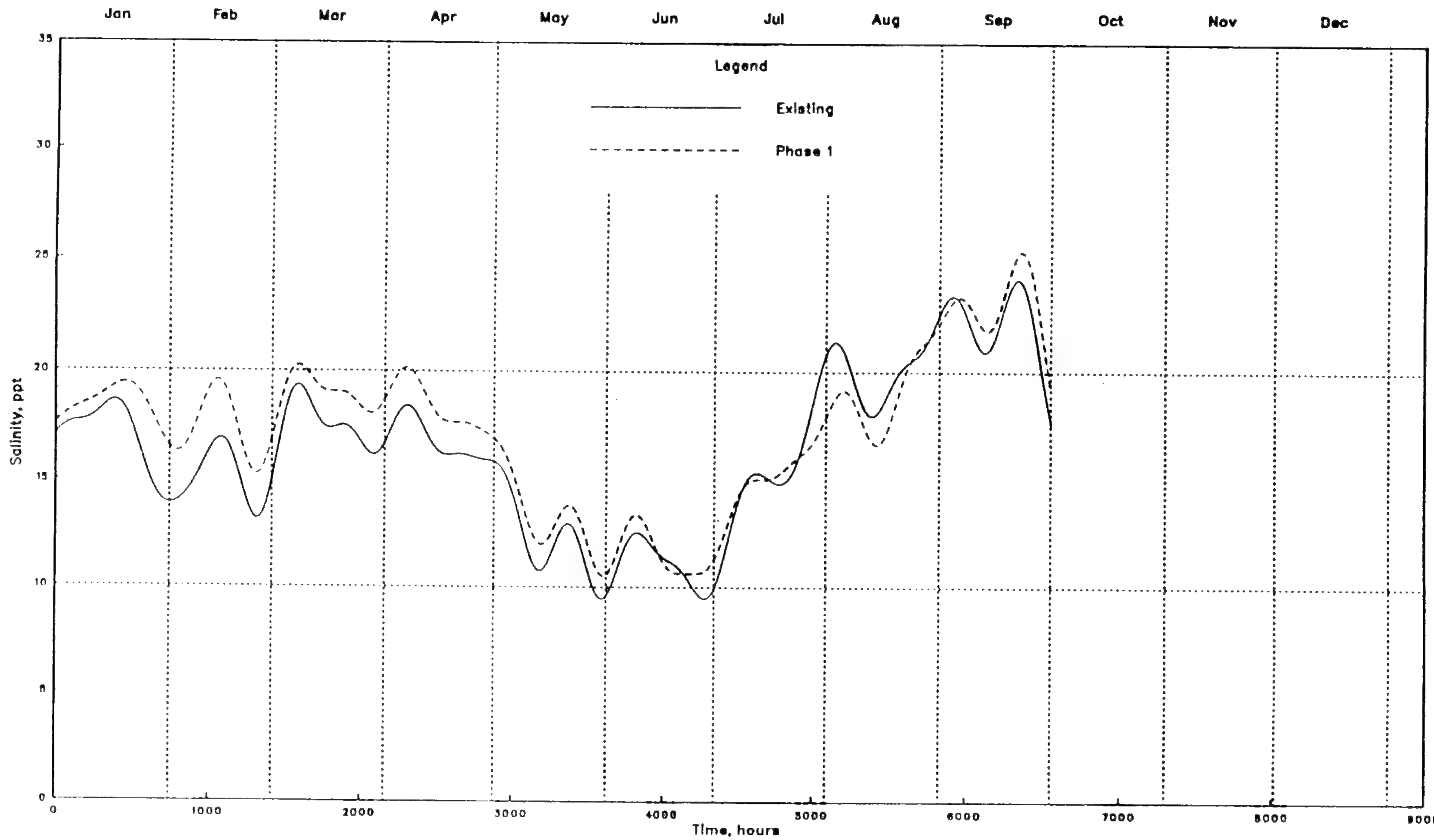
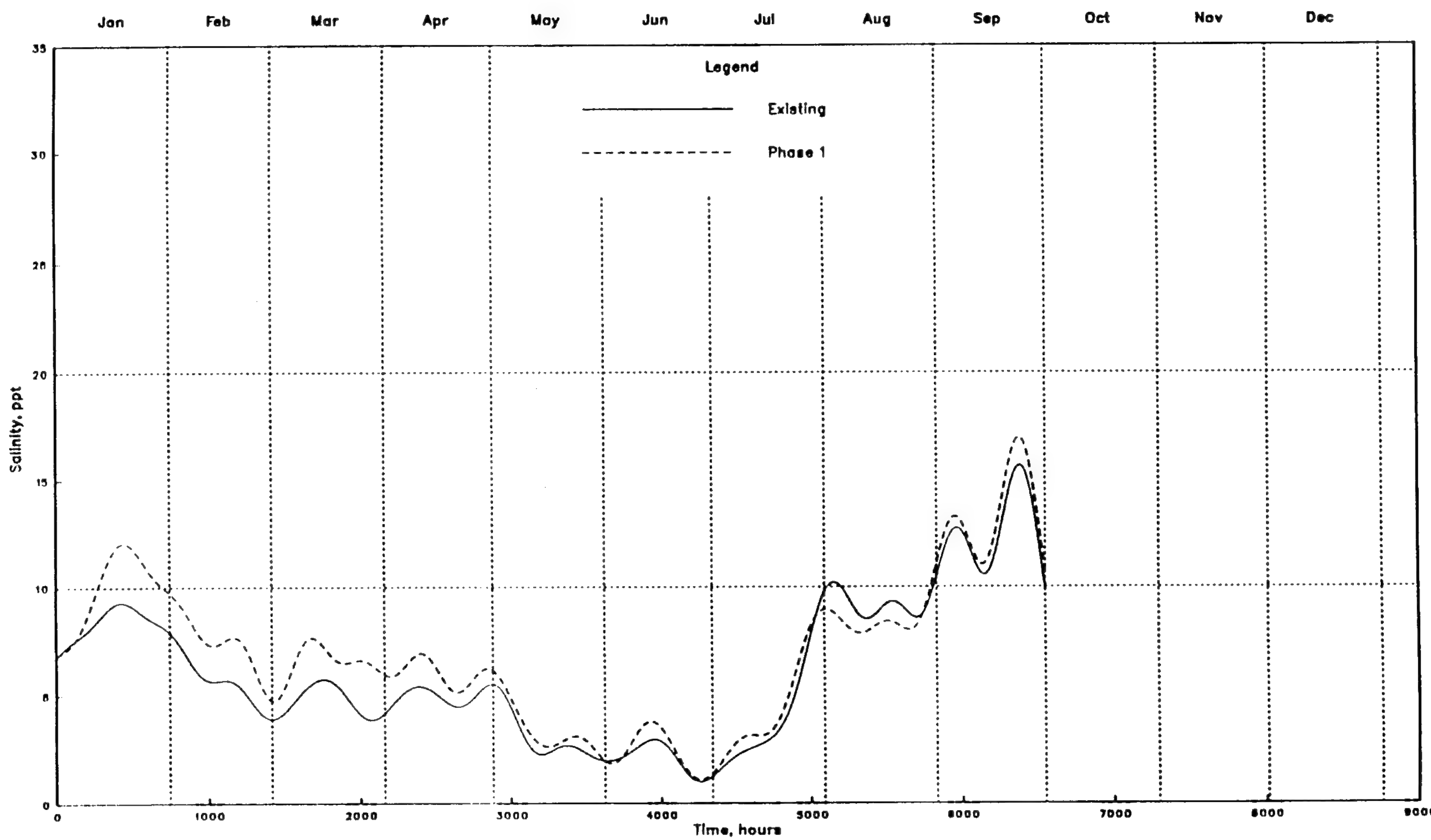
Plate 88



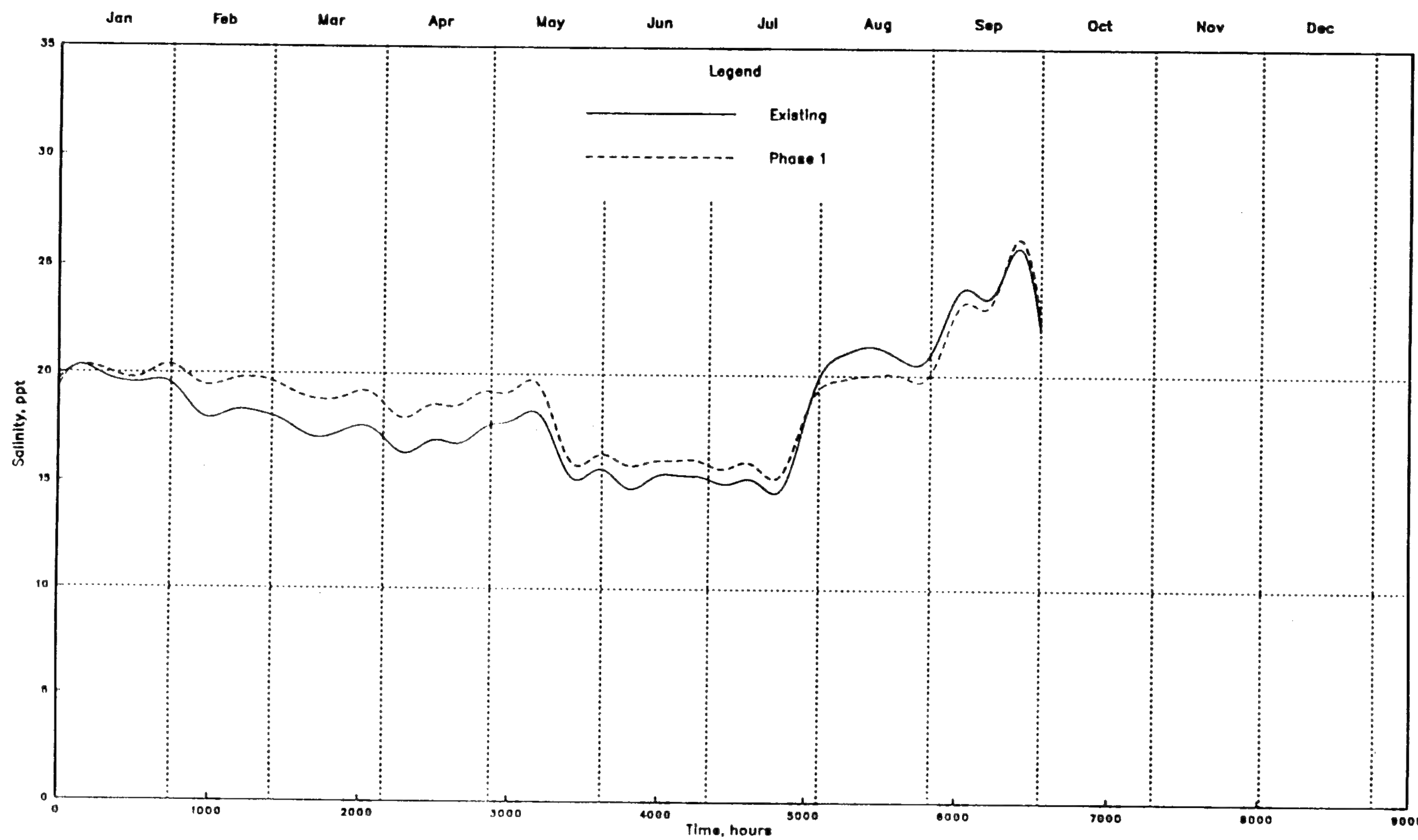
SALINTY TIME SERIES
2024 MEDIUM FLOW
POINT 9



SALINTY TIME SERIES
2024 MEDIUM FLOW
POINT 10



SALINTY TIME SERIES
2024 MEDIUM FLOW
POINT 11



SALINTY TIME SERIES
2024 MEDIUM FLOW
POINT 12

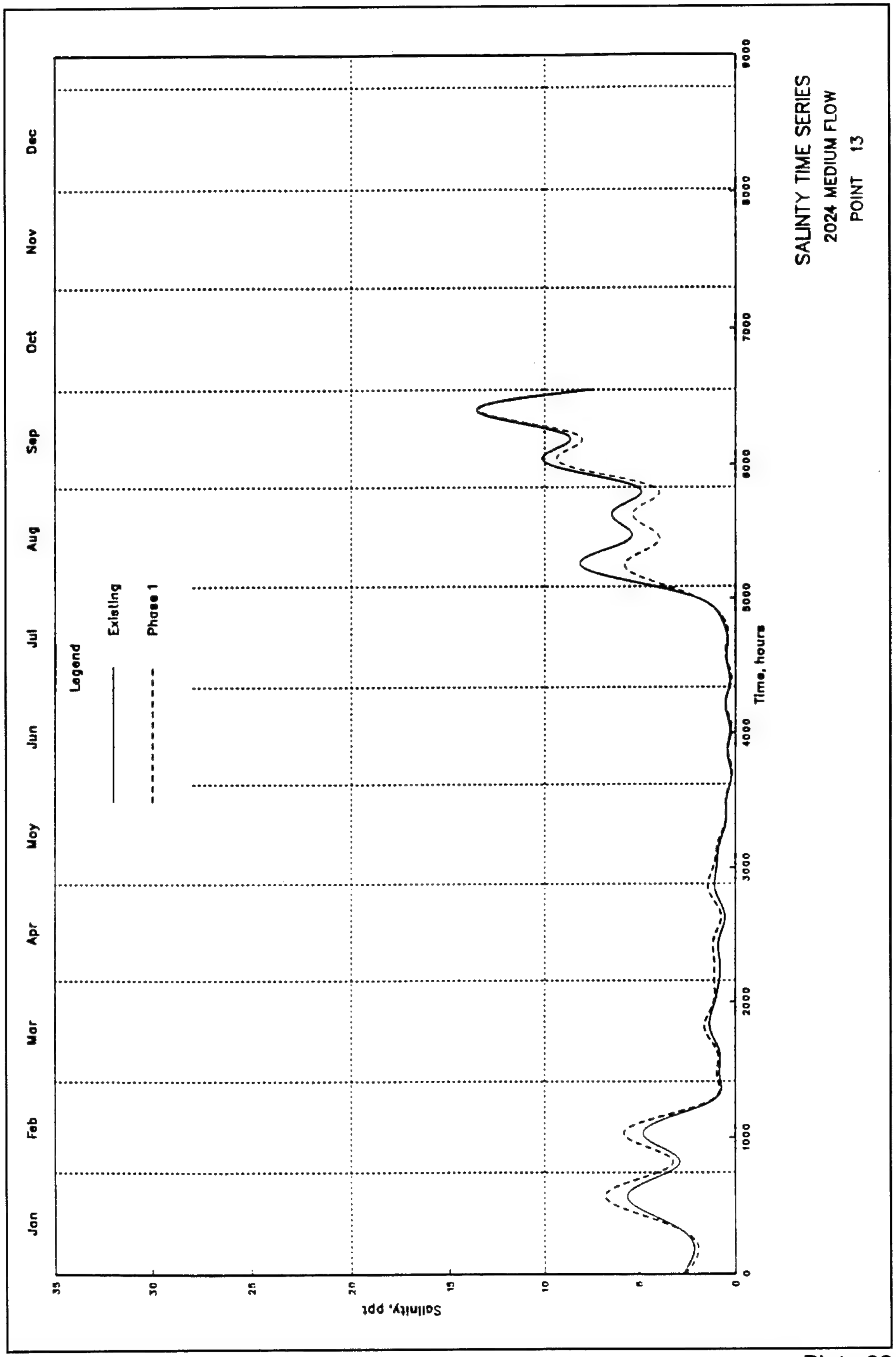

SALINTY TIME SERIES
2024 MEDIUM FLOW
POINT 13
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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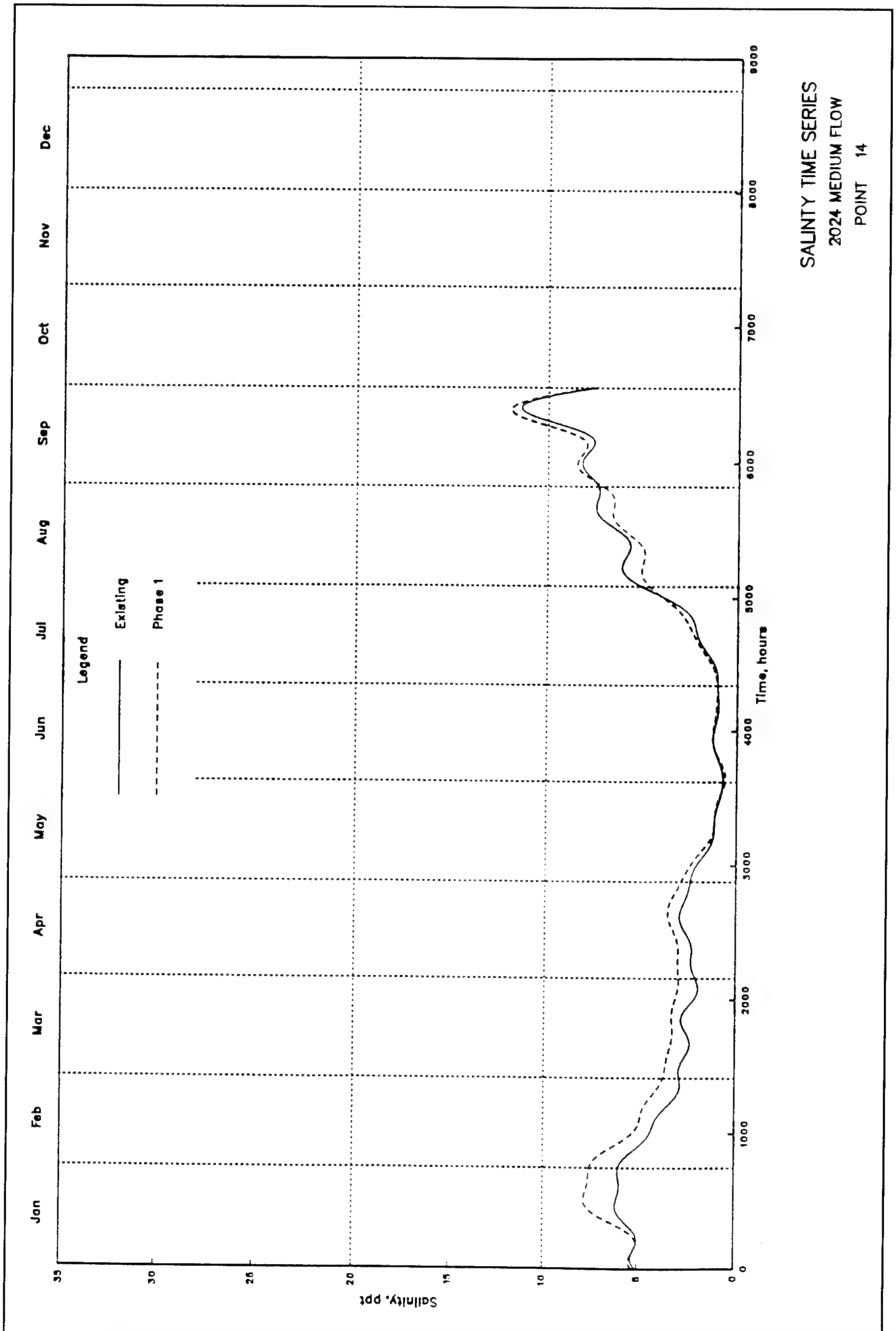
Plate 93



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Phase 1
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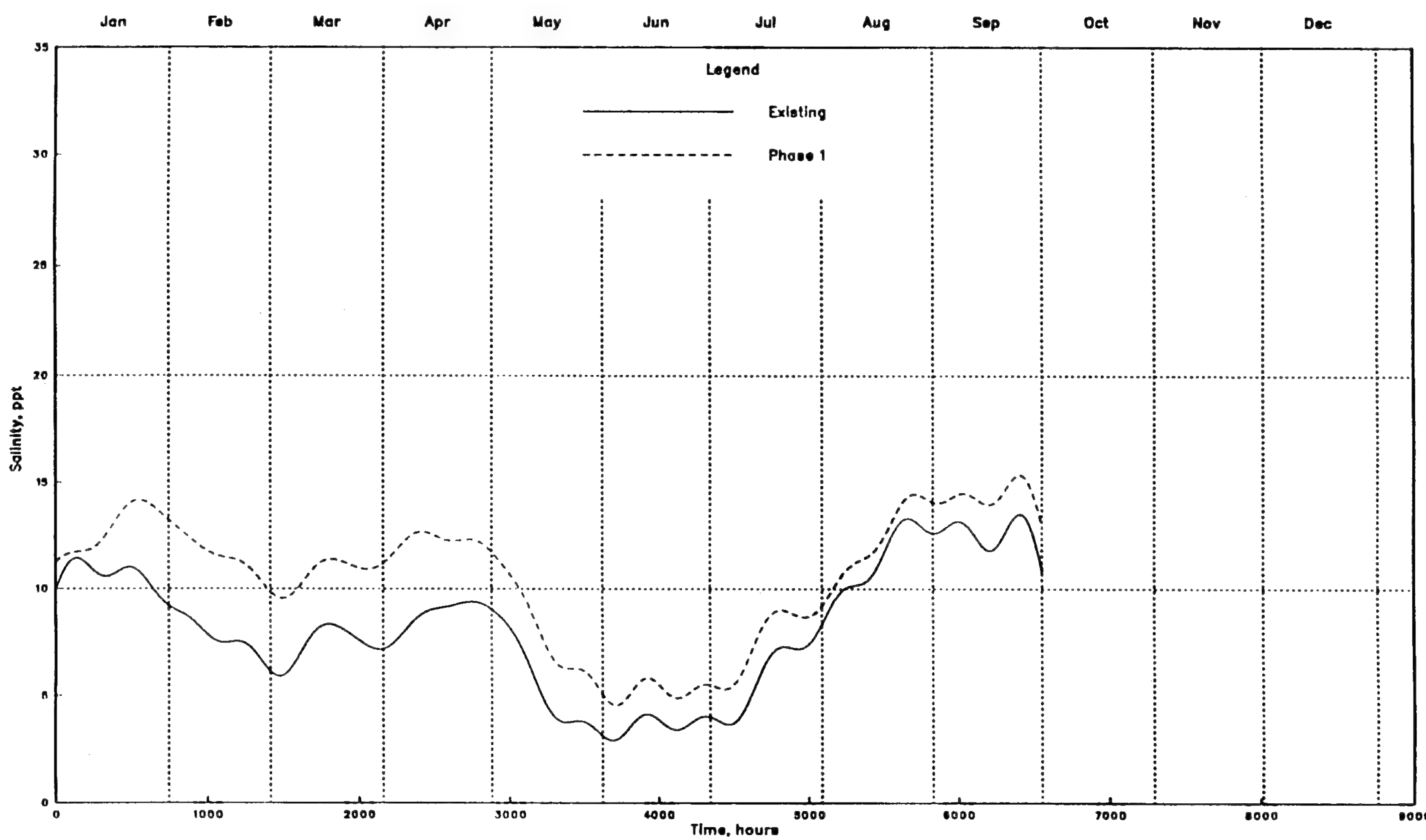
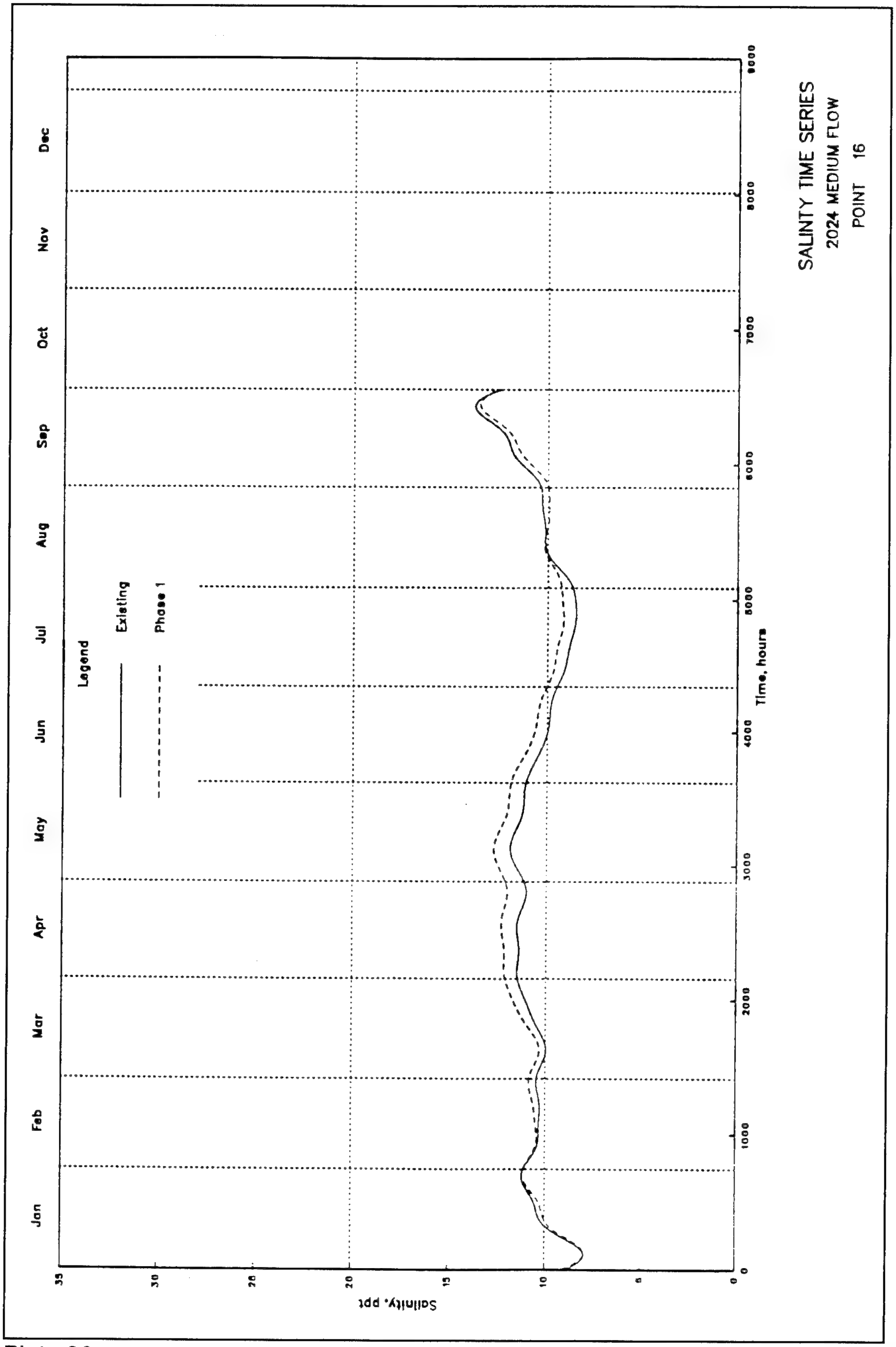
SALINTY TIME SERIES
2024 MEDIUM FLOW
POINT 14

Plate 94



SALINTY TIME SERIES
2024 MEDIUM FLOW
POINT 15



SALINTY TIME SERIES
2024 MEDIUM FLOW
POINT 16
Legend
Existing
Phase 1
Time, hours
Salinity, ppt
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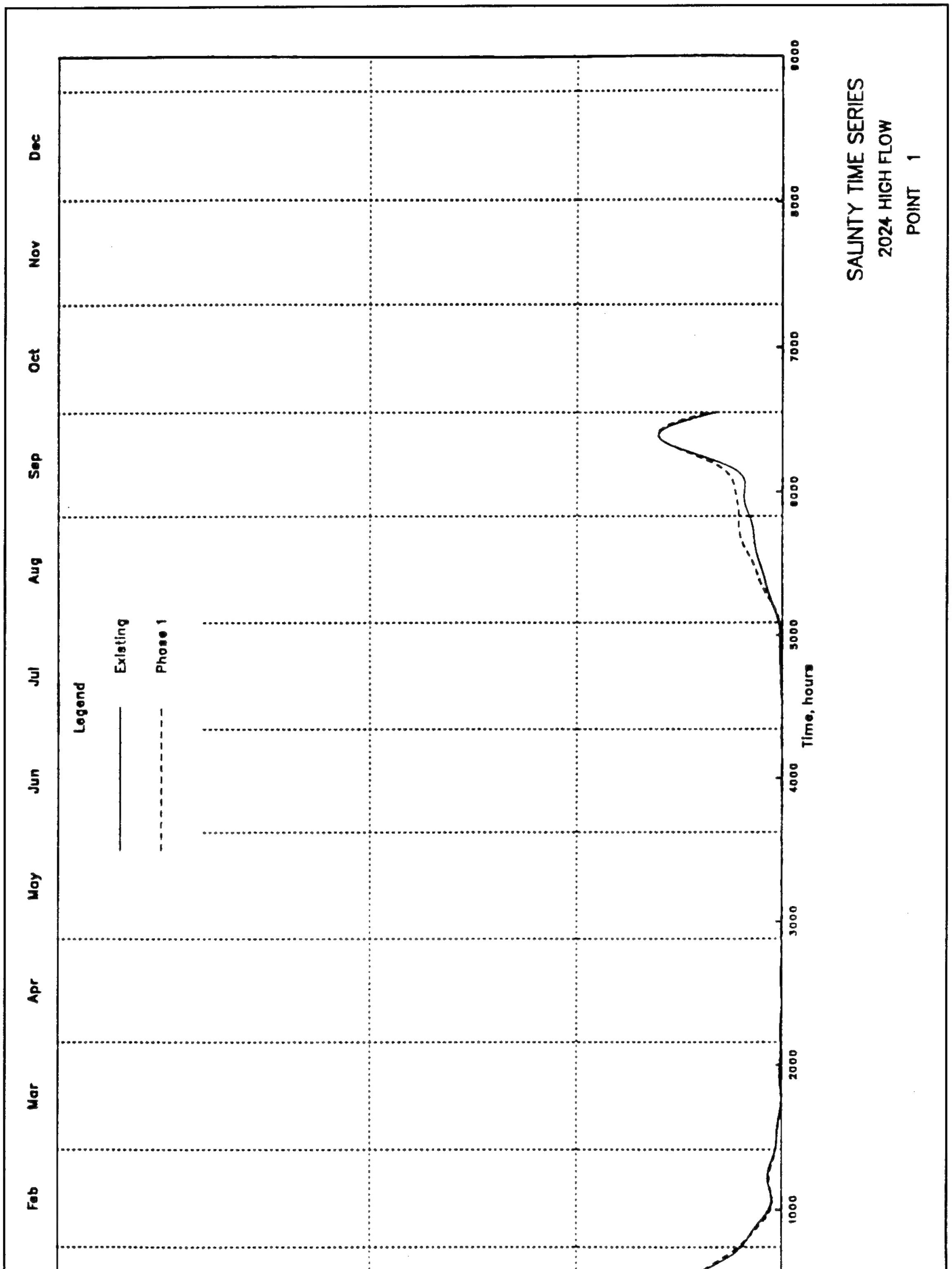
Plate 96



SALINTY TIME SERIES
2024 HIGH FLOW
POINT 1
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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Plate 97

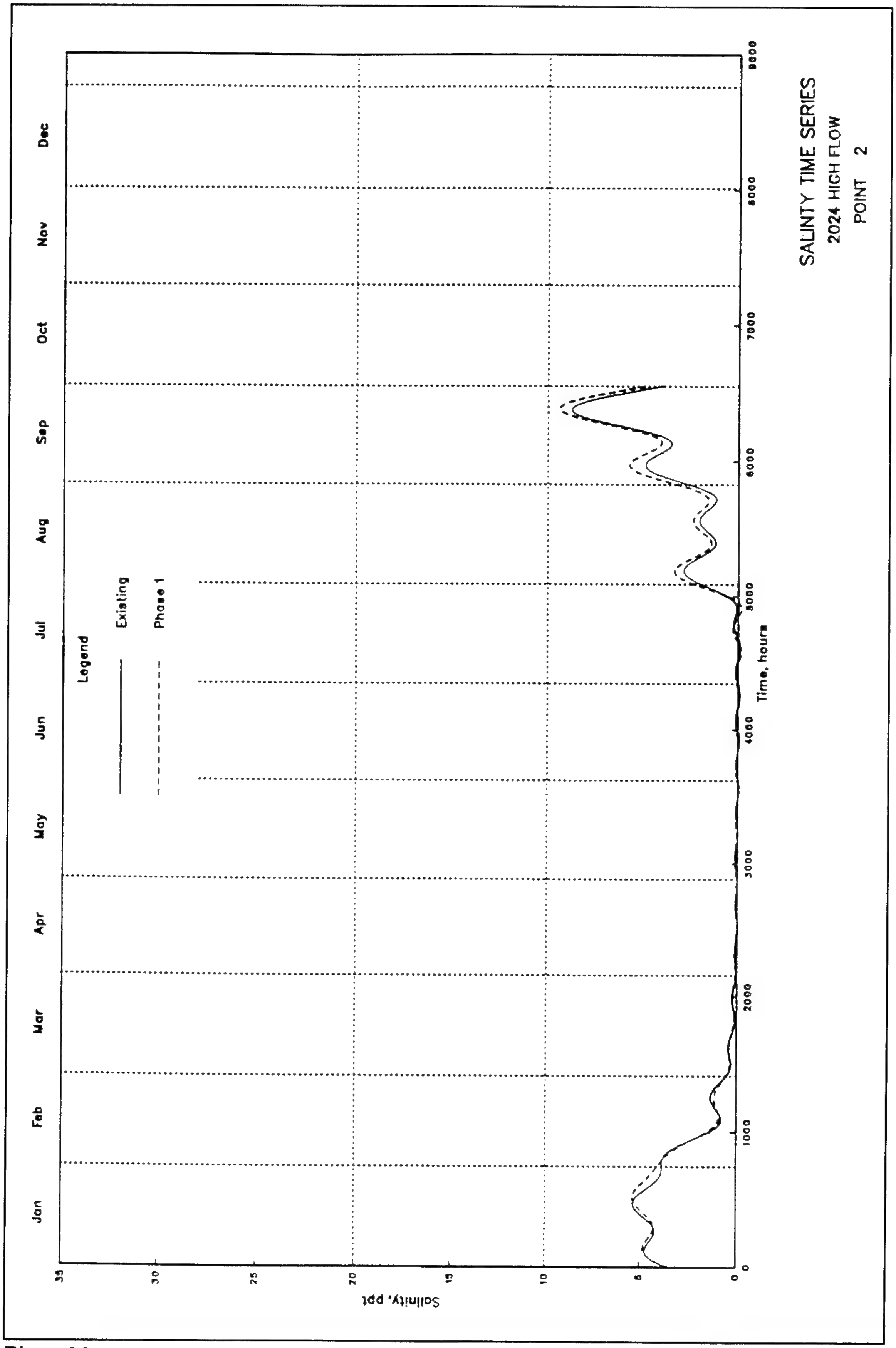
SALINTY TIME SERIES
2024 HIGH FLOW
POINT 2
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
Jan
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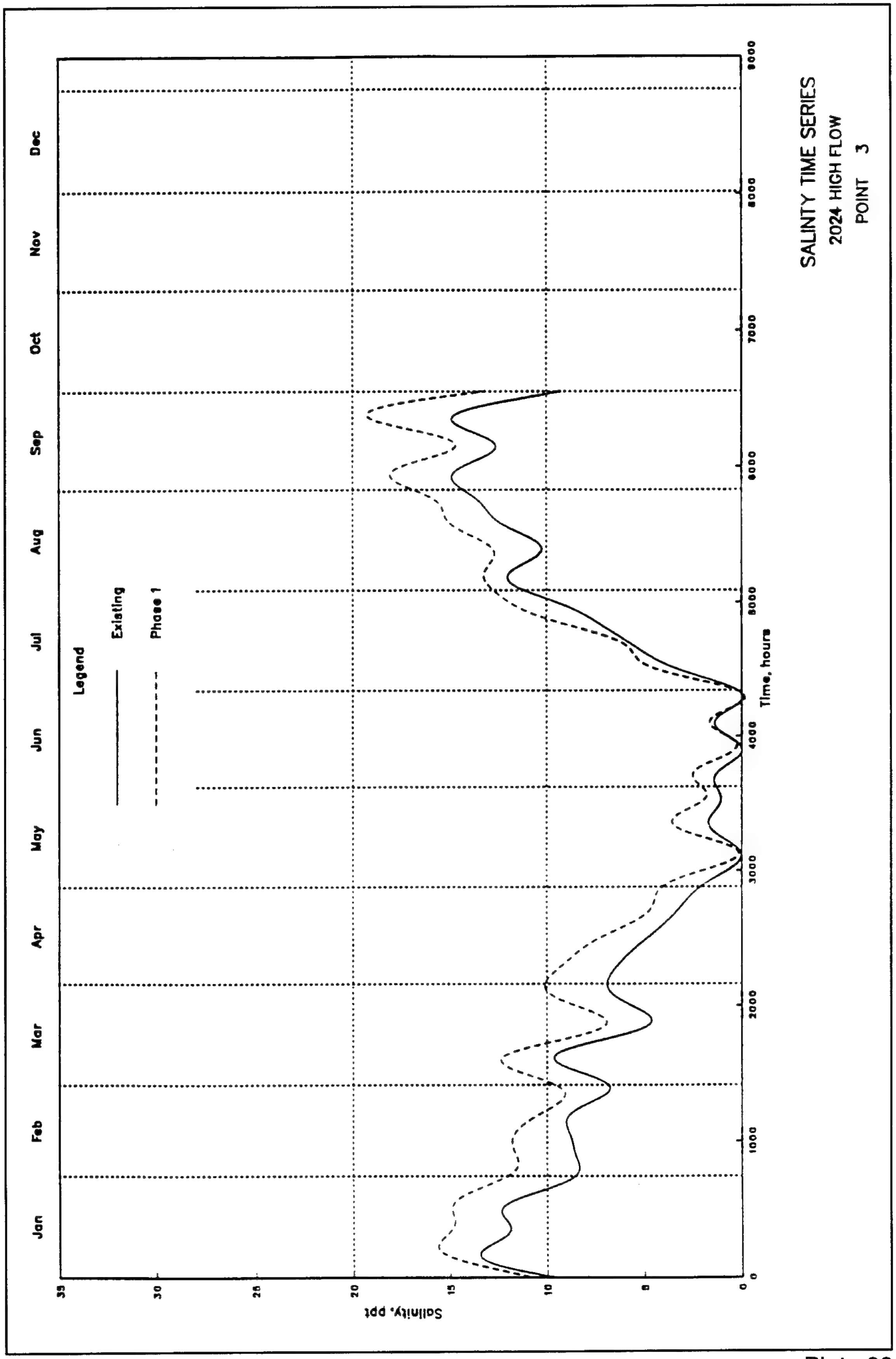
Plate 98


SALINTY TIME SERIES
2024 HIGH FLOW
POINT 3
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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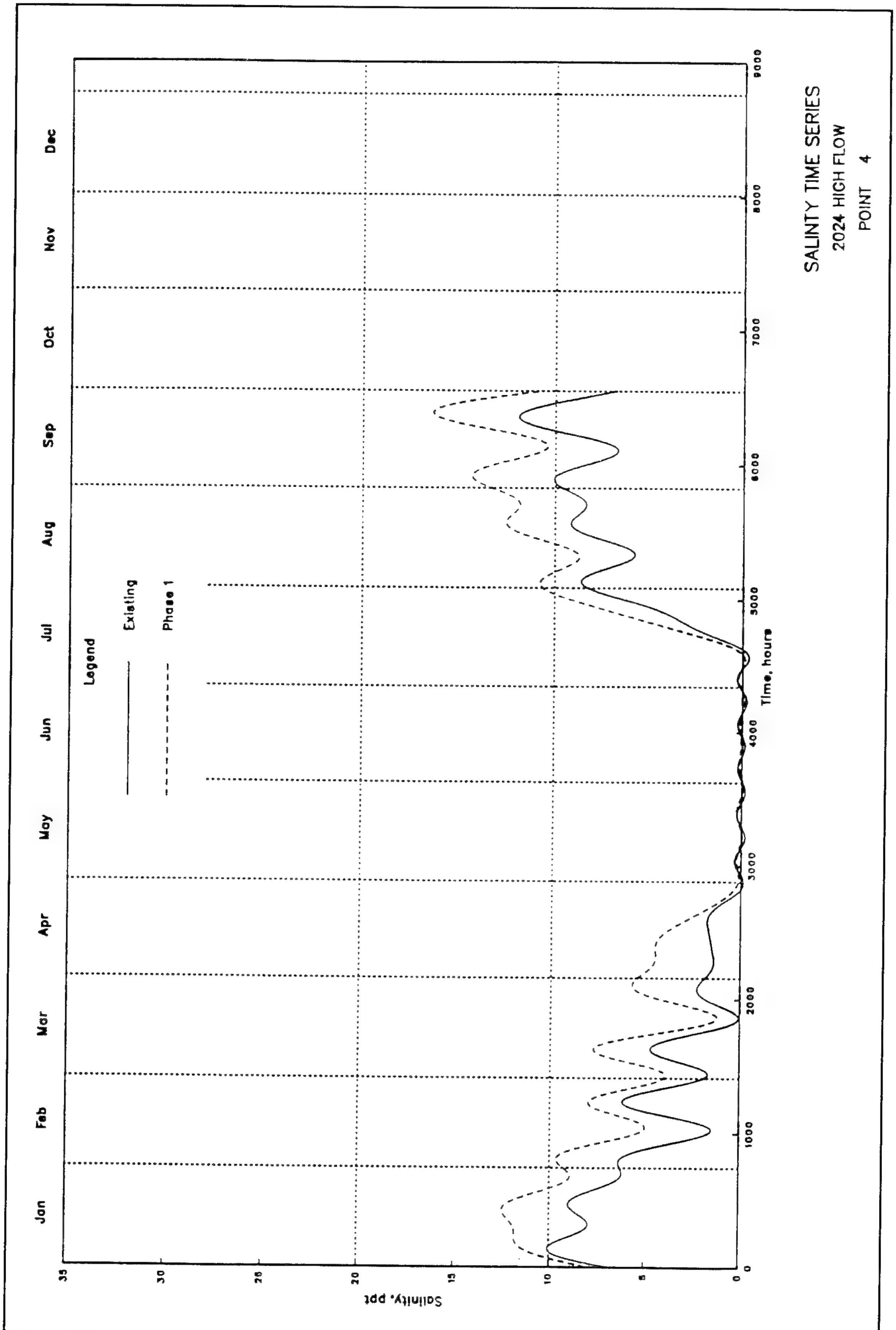
SALINTY TIME SERIES
2024 HIGH FLOW
POINT 4
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
Jan
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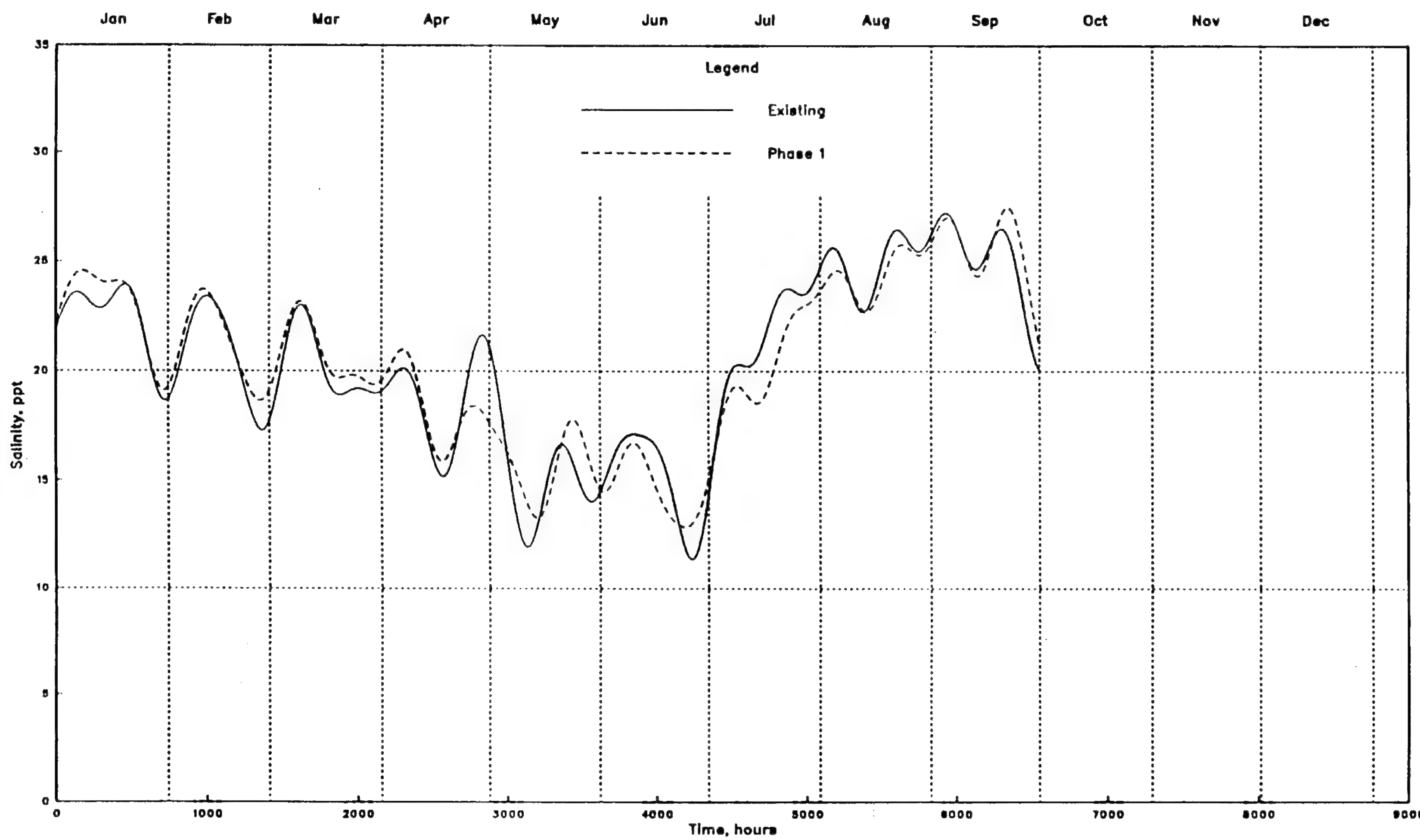
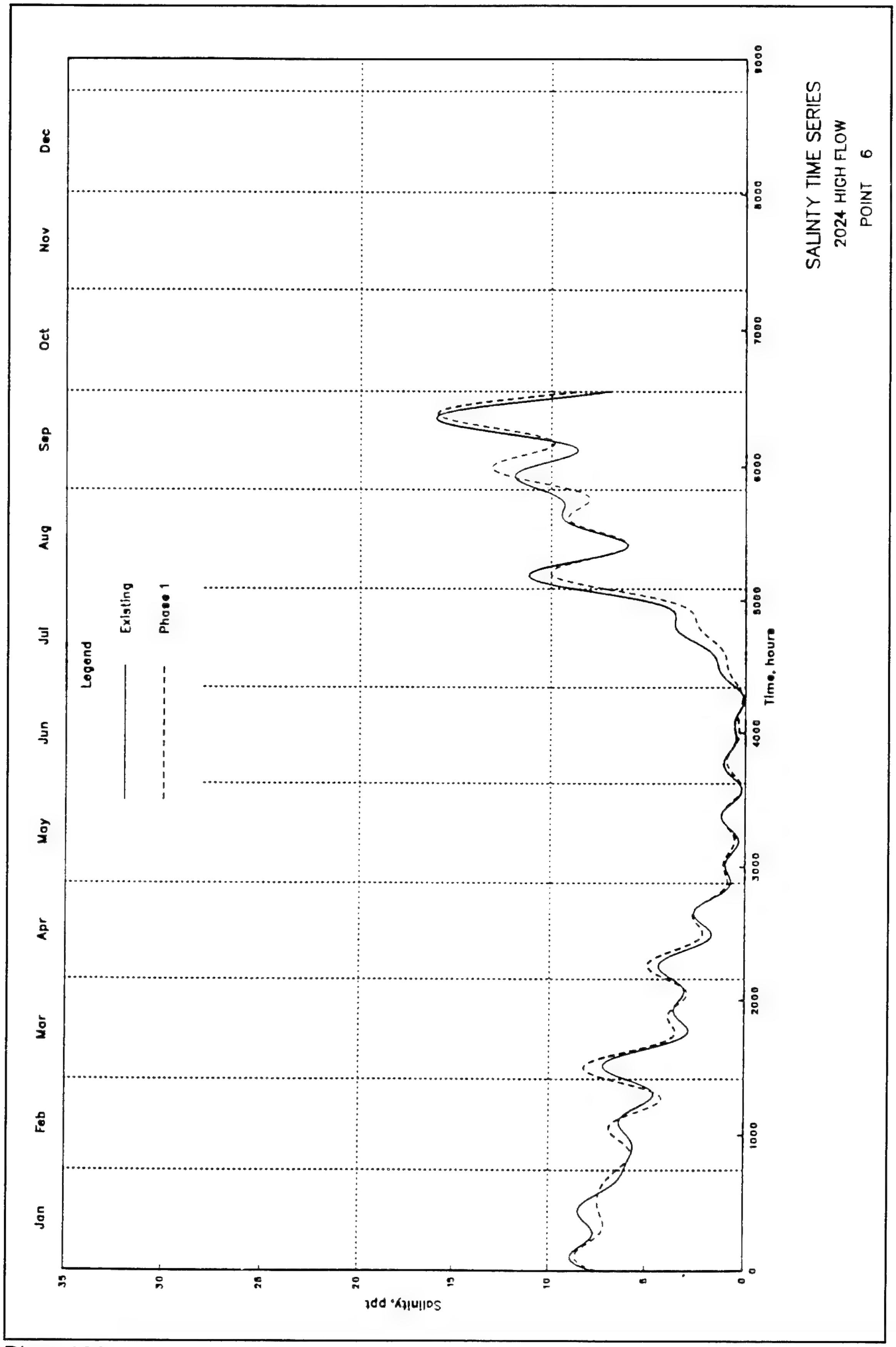
Plate 100



SALINTY TIME SERIES
2024 HIGH FLOW
POINT 5



SALINTY TIME SERIES
2024 HIGH FLOW
POINT 6
Legend
Existing
Phase 1
Jan
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Salinity, ppt
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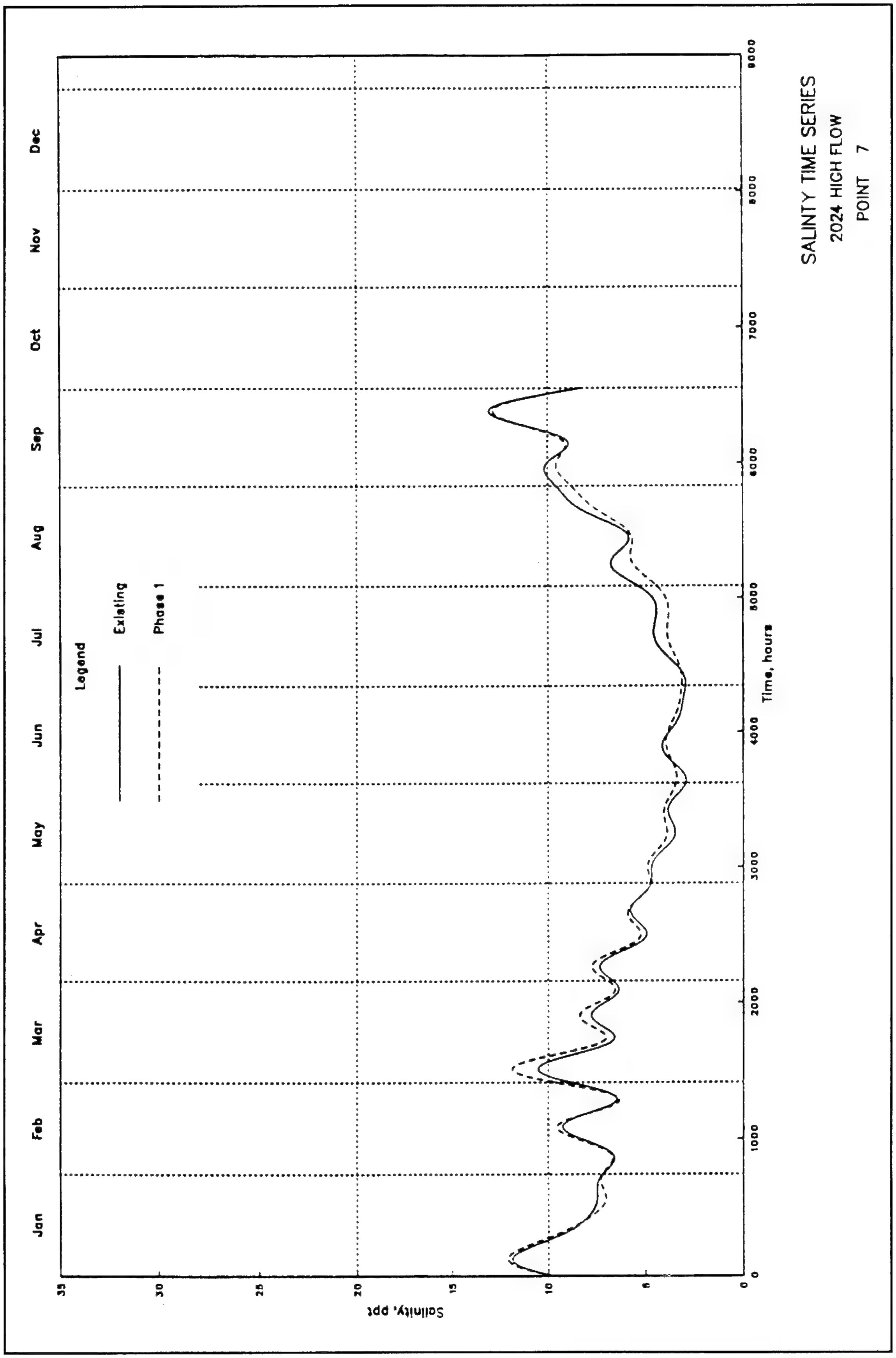
Plate 102


SALINTY TIME SERIES
2024 HIGH FLOW
POINT 7
Legend
Existing
Phase 1
Jan
Feb
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Salinity, ppt
Time, hours
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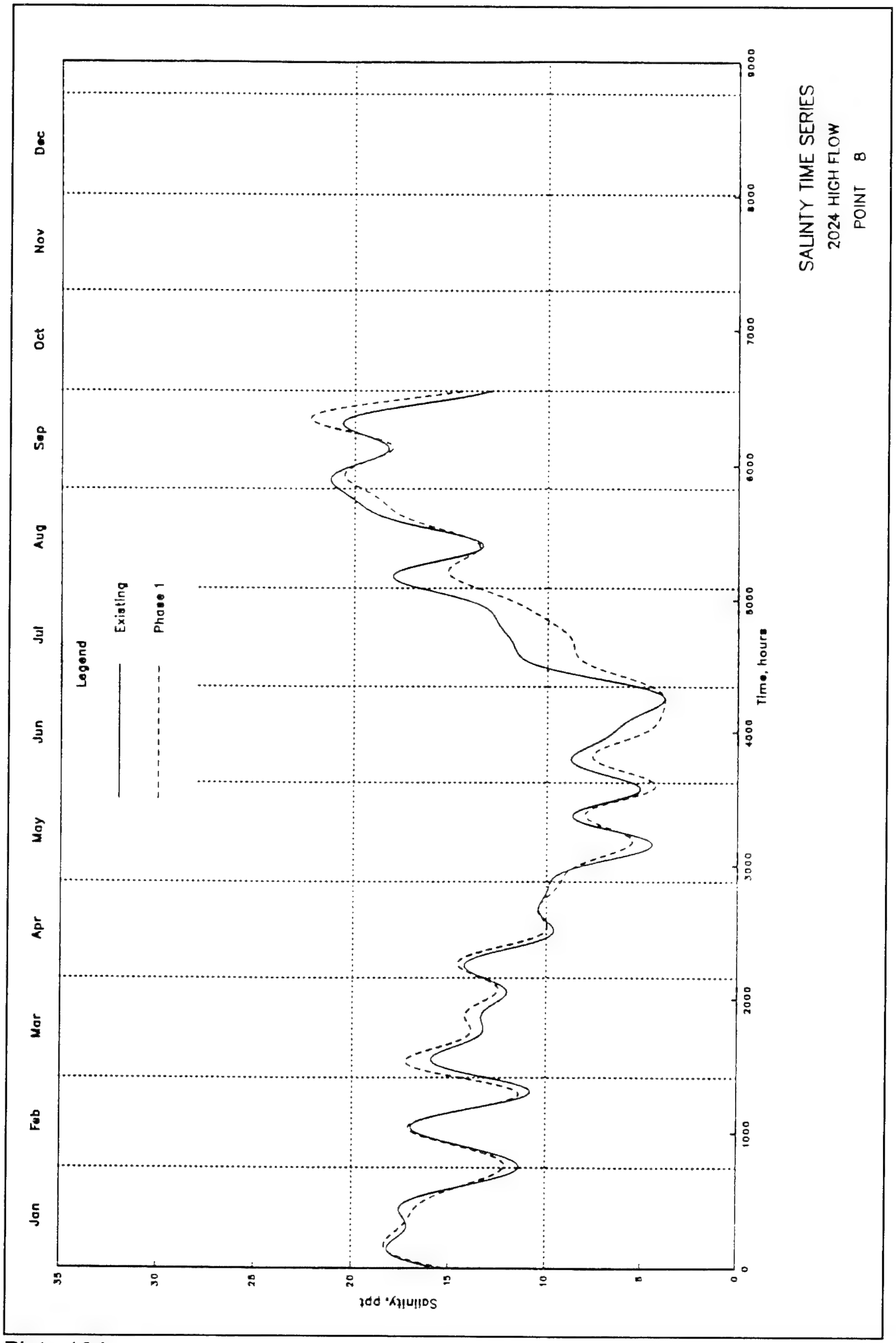
Plate 103


SALINTY TIME SERIES
2024 HIGH FLOW
POINT 8
Legend
Existing
Phase 1
Jan
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Time, hours
Salinity, ppt
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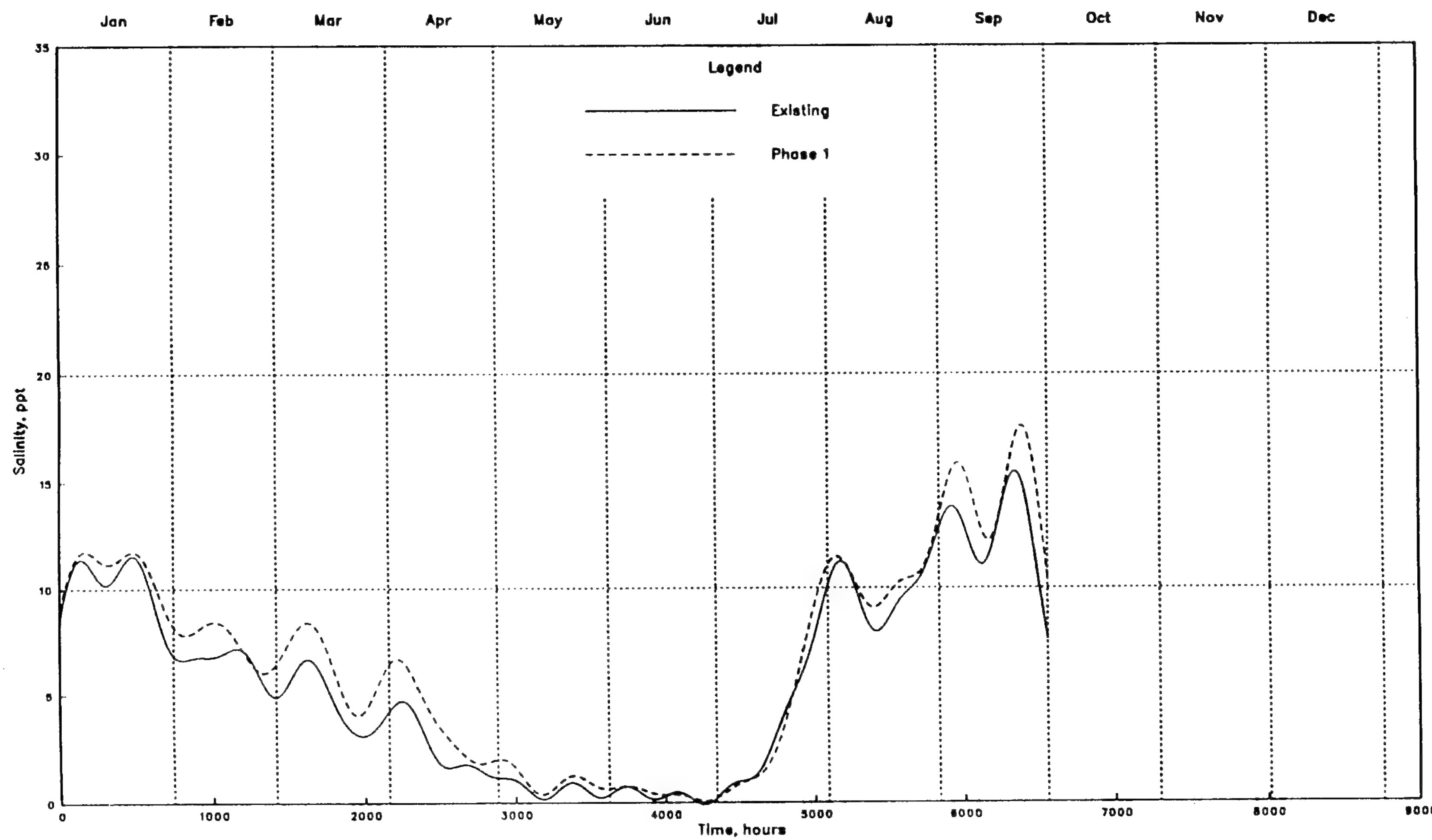
Plate 104



SALINTY TIME SERIES
2024 HIGH FLOW
POINT 9

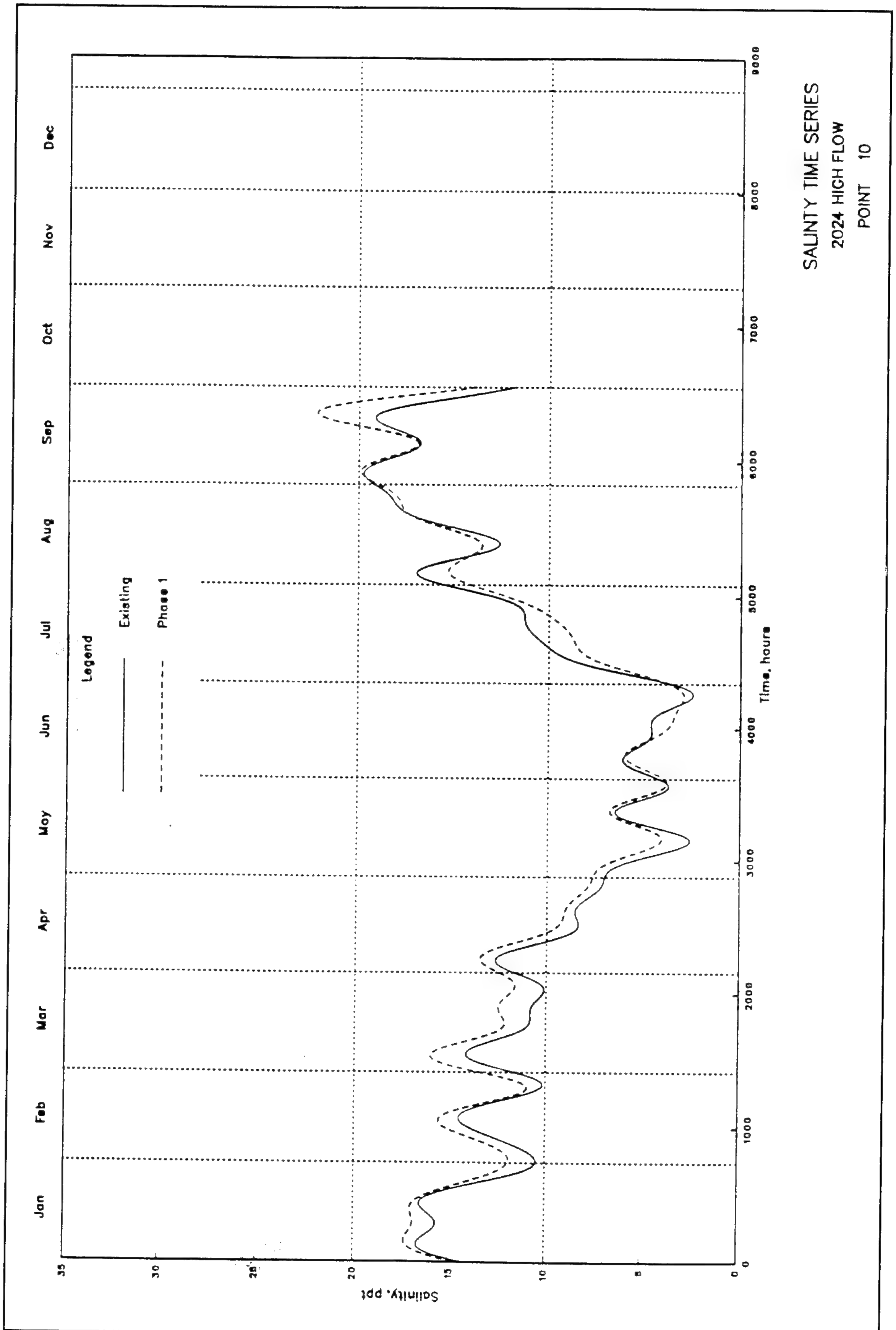

SALINTY TIME SERIES
2024 HIGH FLOW
POINT 10
Legend
Existing
Phase 1
Time, hours
Salinity, ppt
Jan
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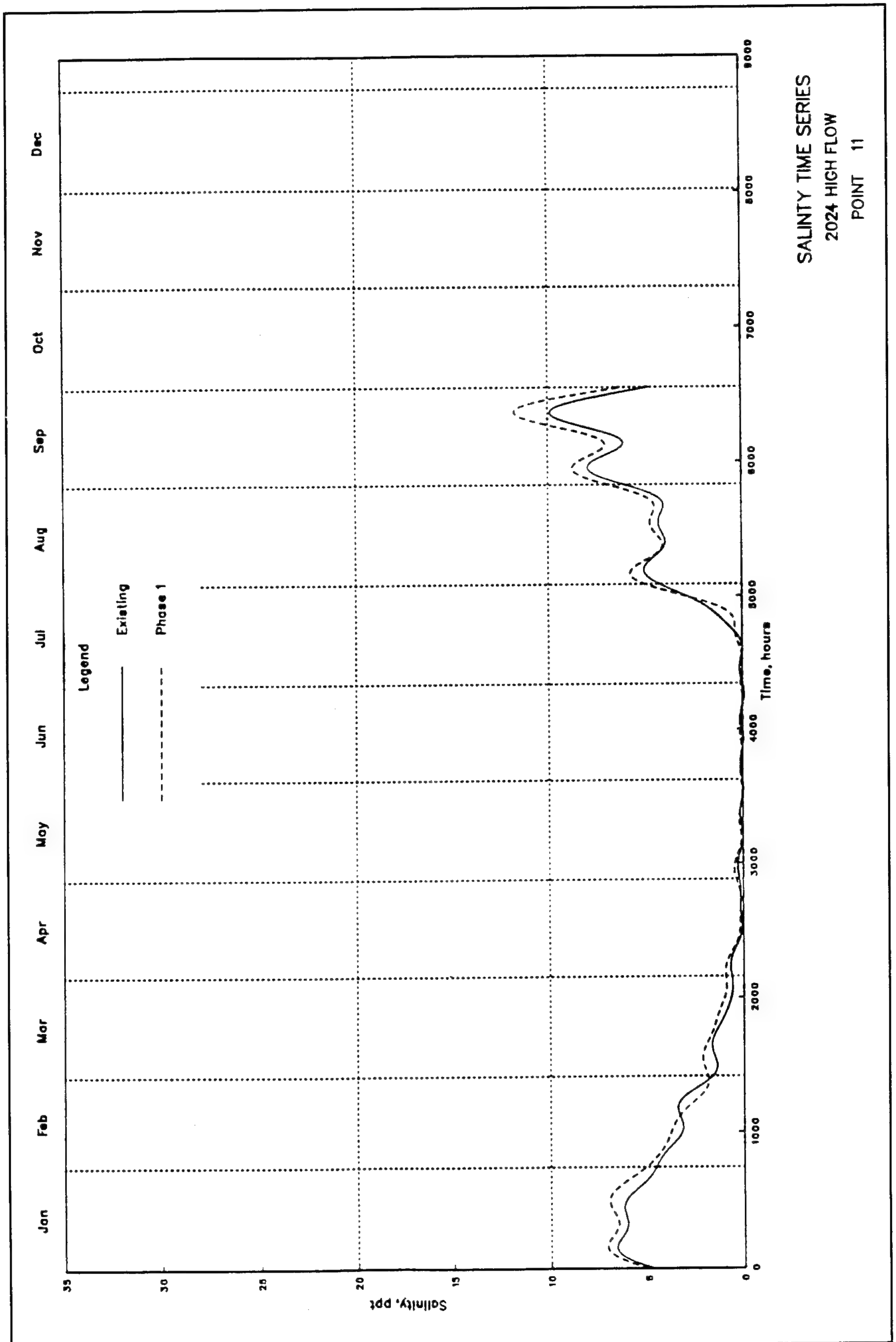
Plate 106



SALINTY TIME SERIES
2024 HIGH FLOW
POINT 11
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
Jan
Feb
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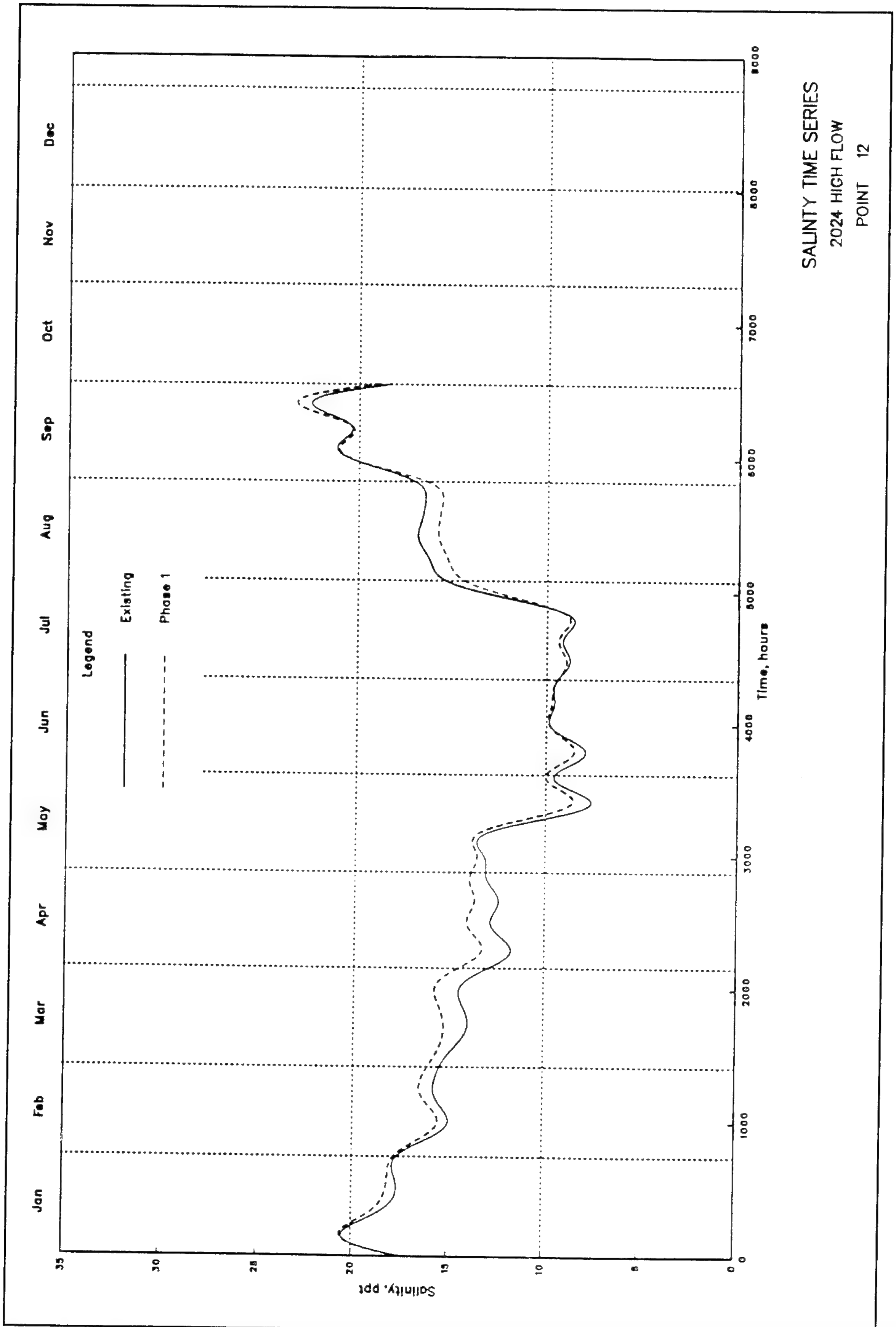
SALINTY TIME SERIES
2024 HIGH FLOW
POINT 12
Legend
Existing
Phase 1
Time, hours
Salinity, ppt
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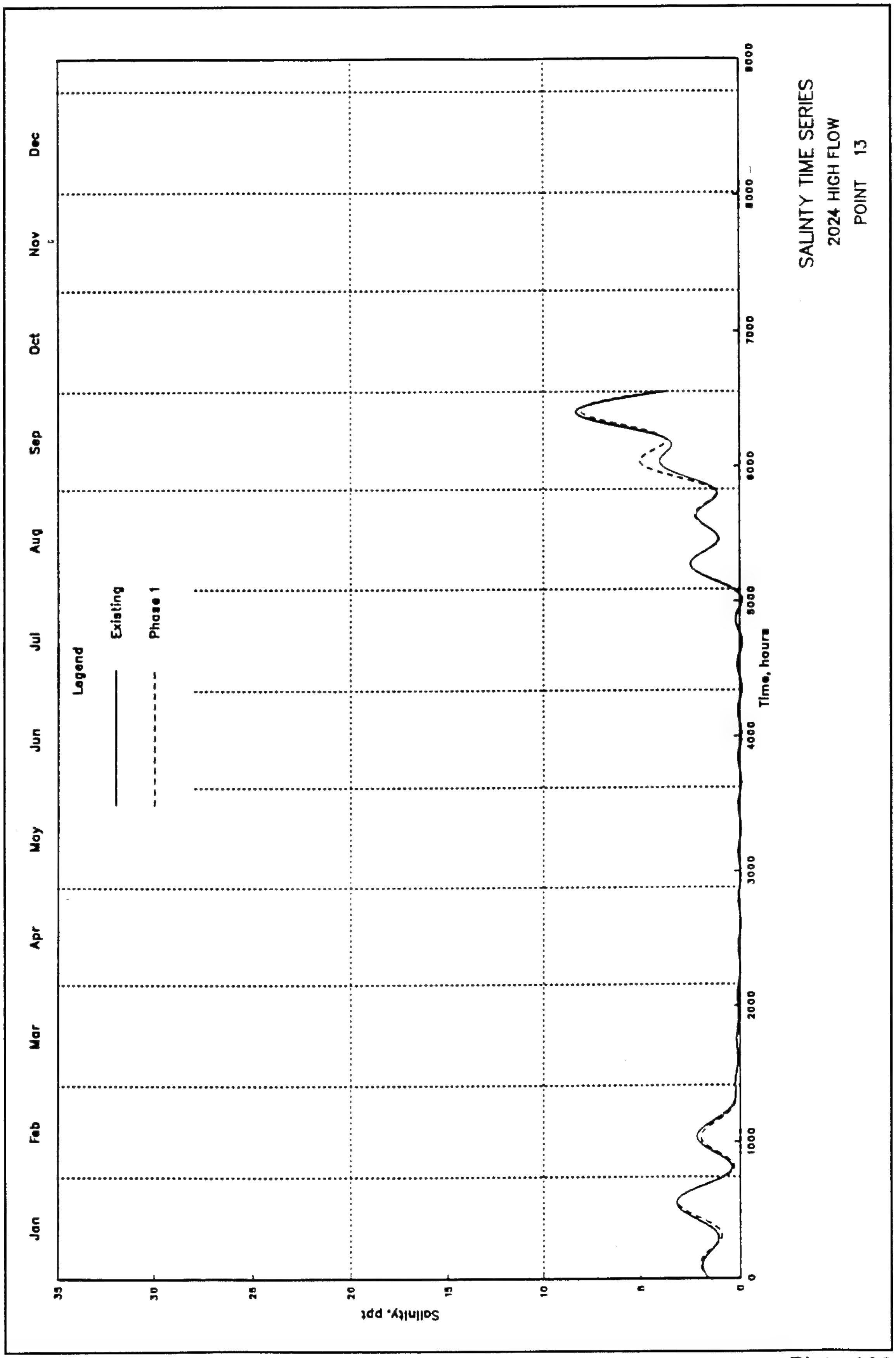
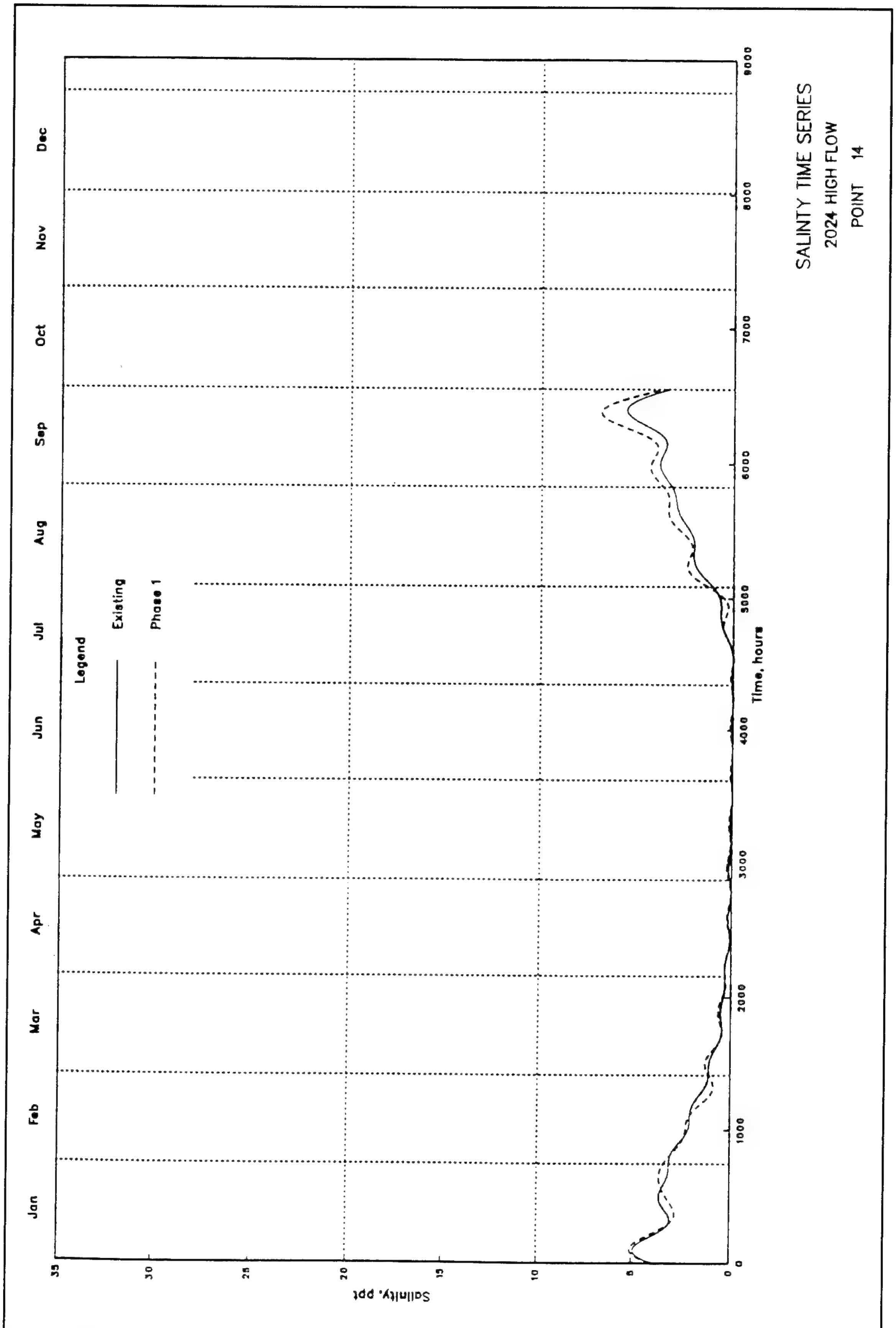
Plate 108



SALINTY TIME SERIES
2024 HIGH FLOW
POINT 13

Plate 109



SALINTY TIME SERIES
2024 HIGH FLOW
POINT 14
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
Jan
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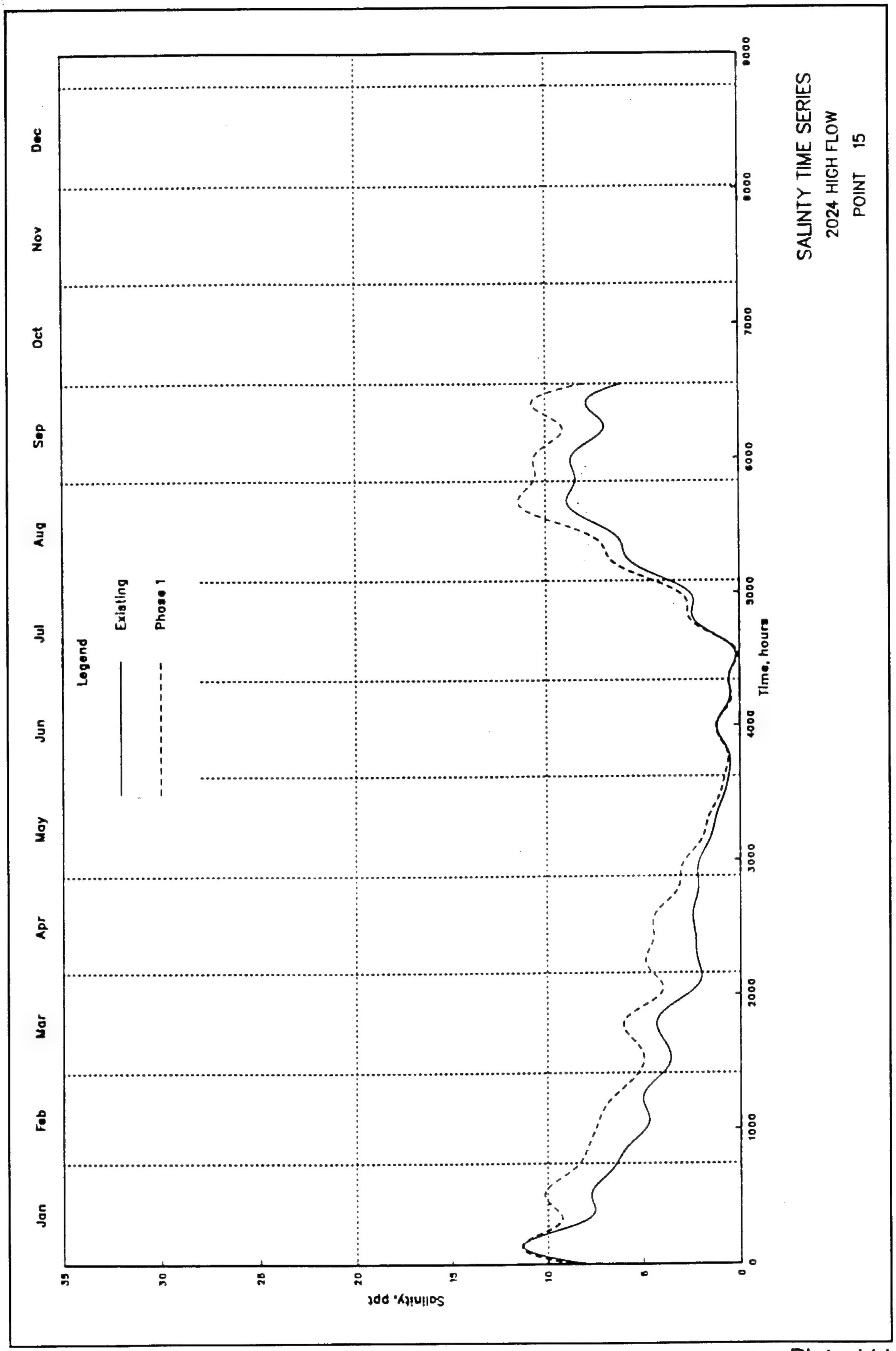
Plate 110



SALINTY TIME SERIES
2024 HIGH FLOW
POINT 15
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
Jan
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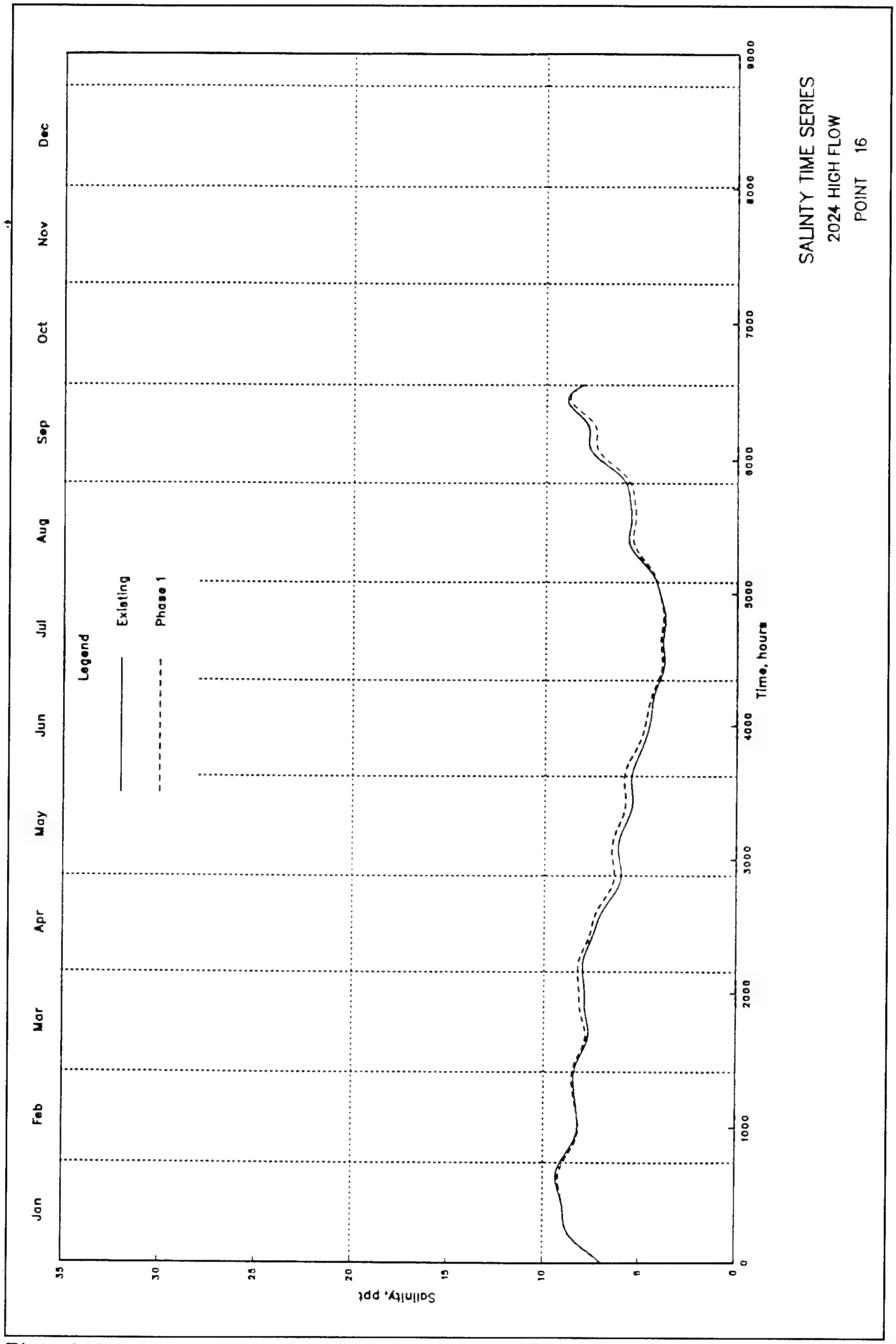
SALINTY TIME SERIES
2024 HIGH FLOW
POINT 16
Legend
Existing
Phase 1
Time, hours
Salinity, ppt
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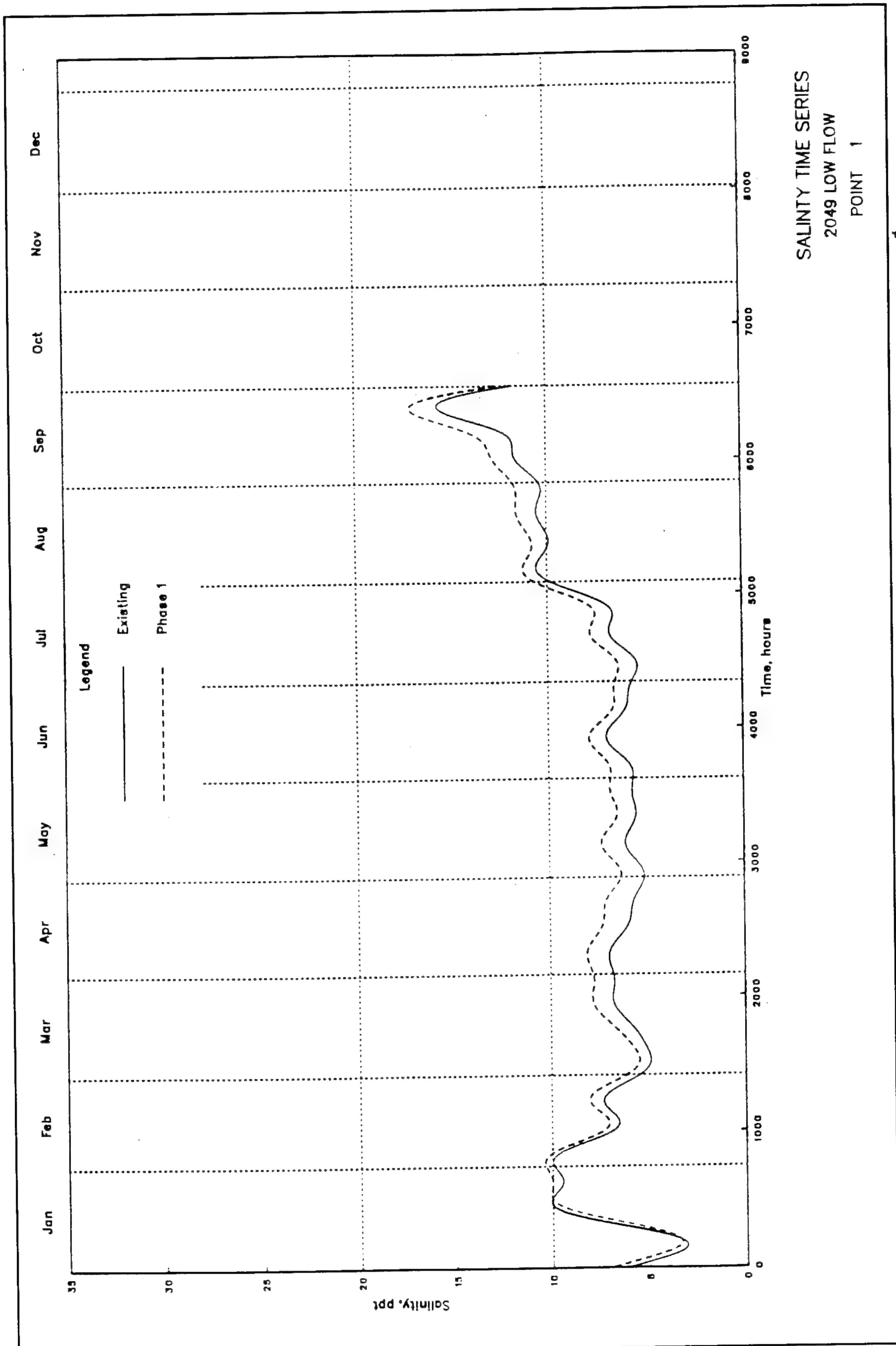
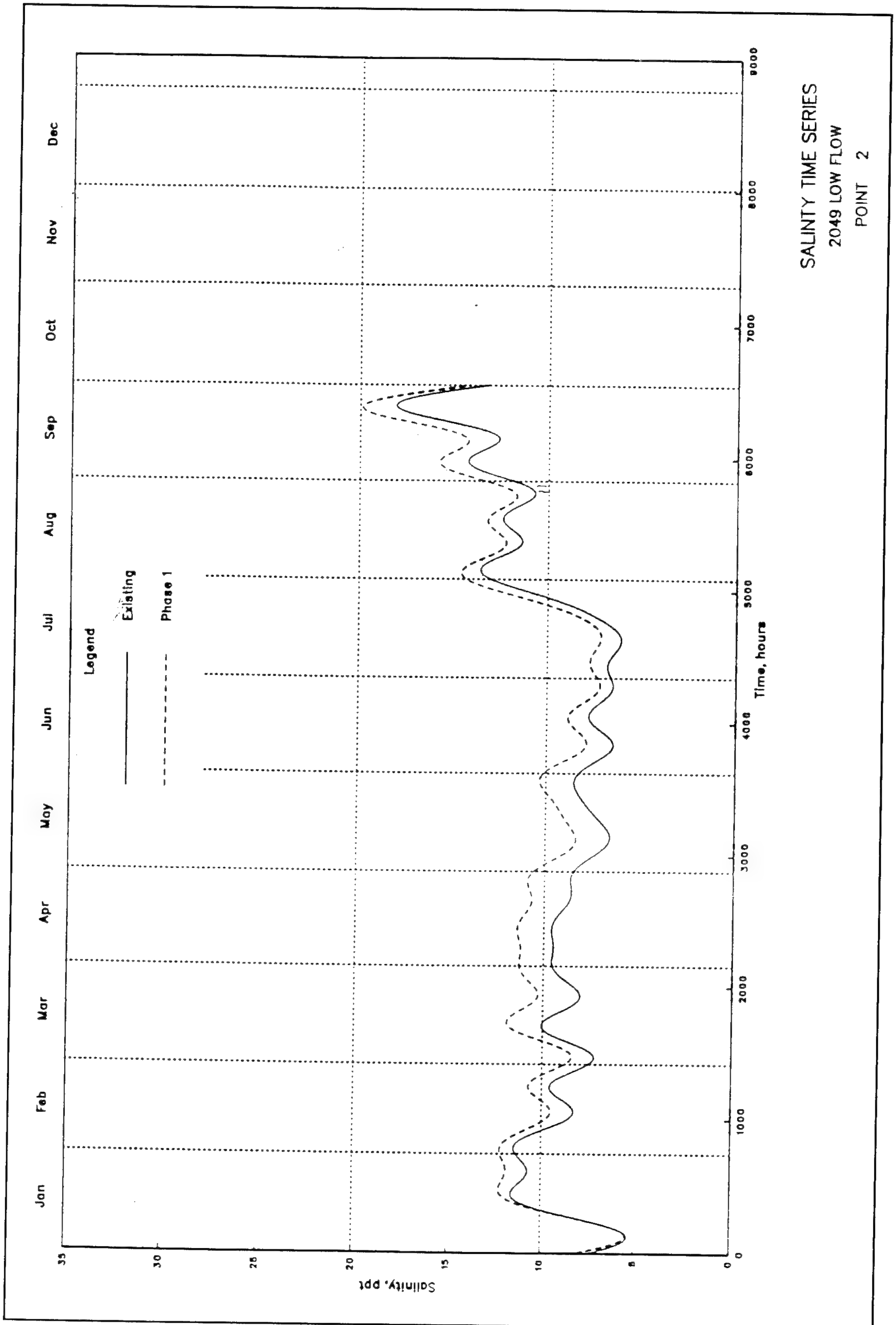
Plate 112



SALINTY TIME SERIES
2049 LOW FLOW
POINT 1



SALINTY TIME SERIES
2049 LOW FLOW
POINT 2
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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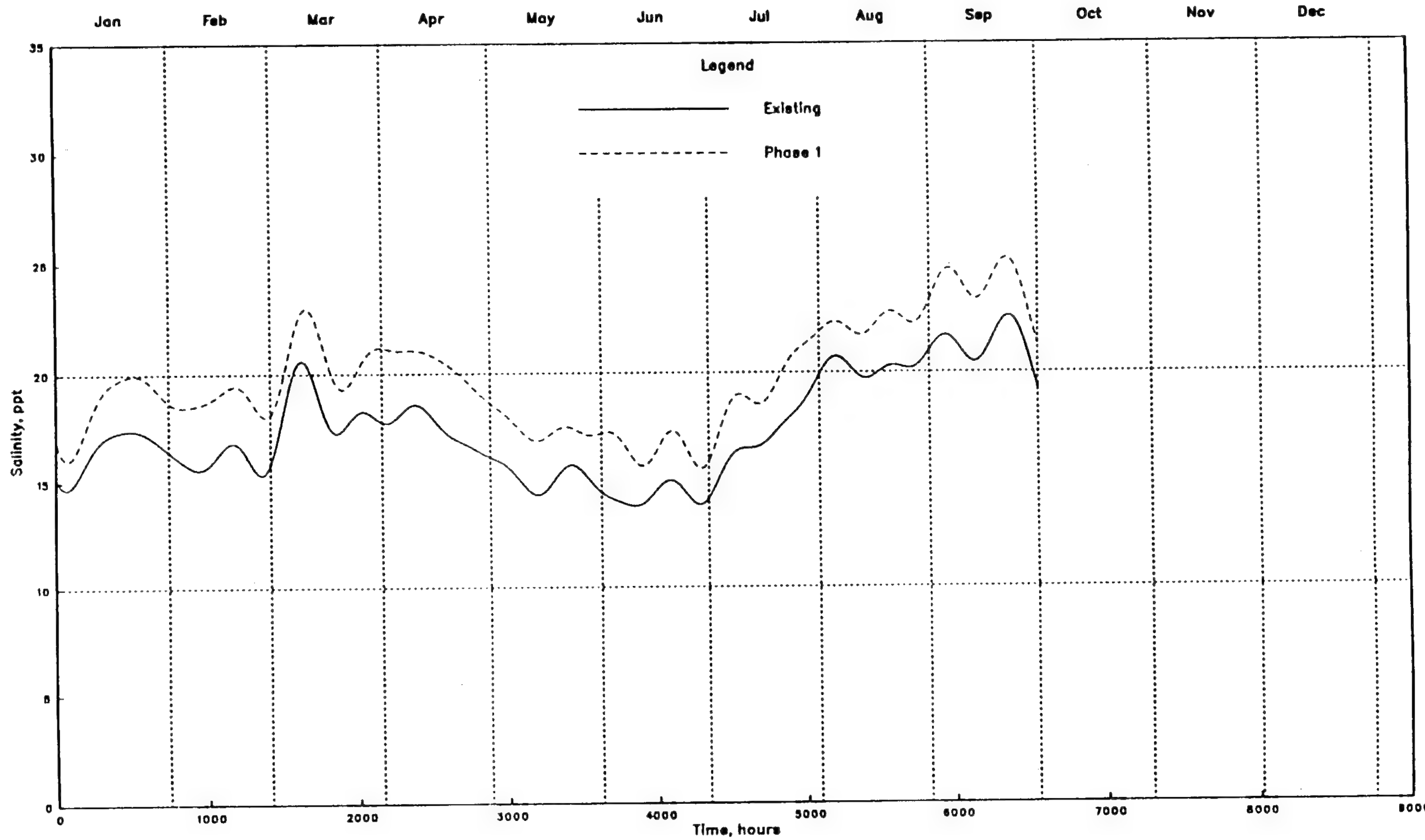
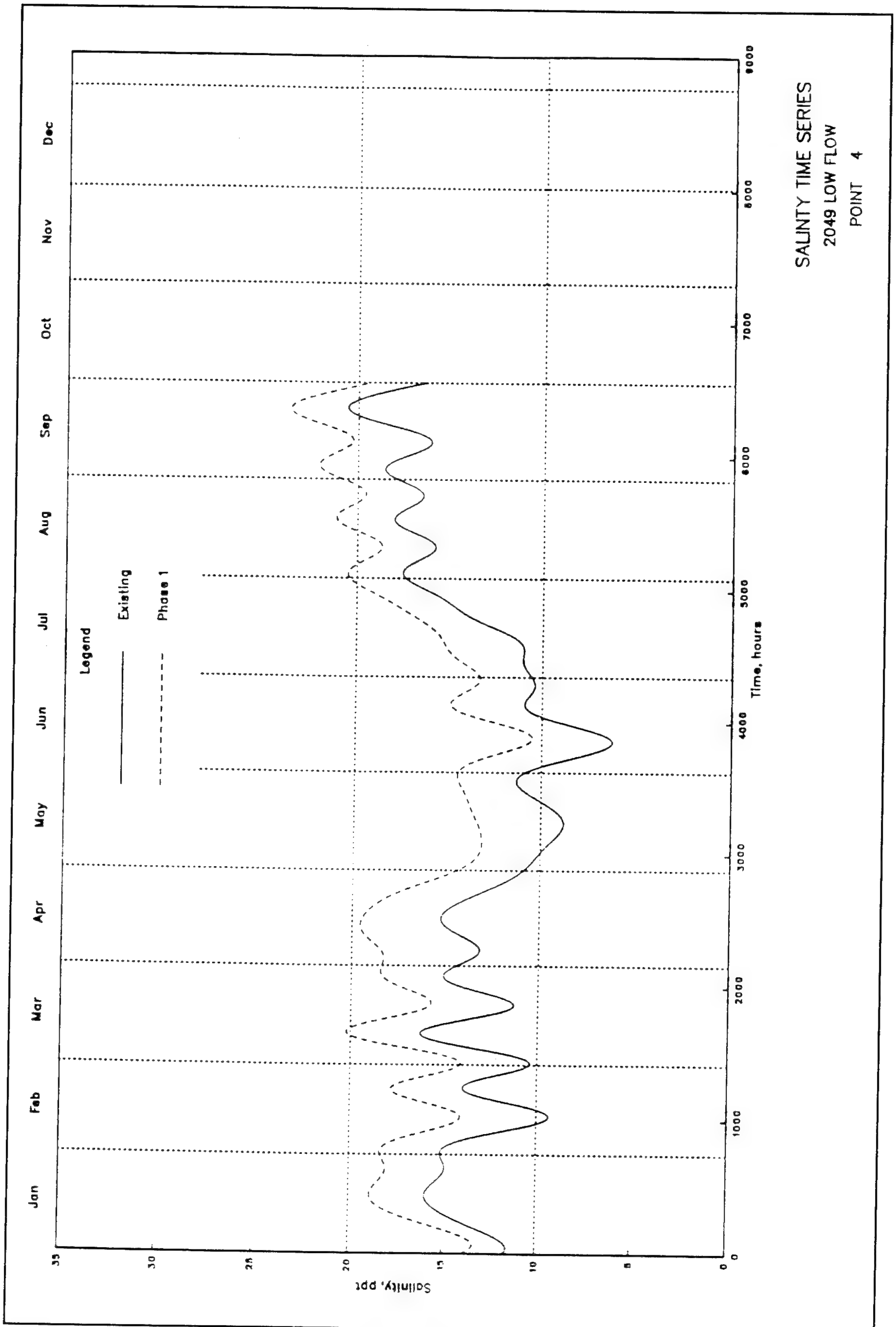
Plate 114



SALINTY TIME SERIES
2049 LOW FLOW
POINT 3


SALINTY TIME SERIES
2049 LOW FLOW
POINT 4
Legend
Existing
Phase 1
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Feb
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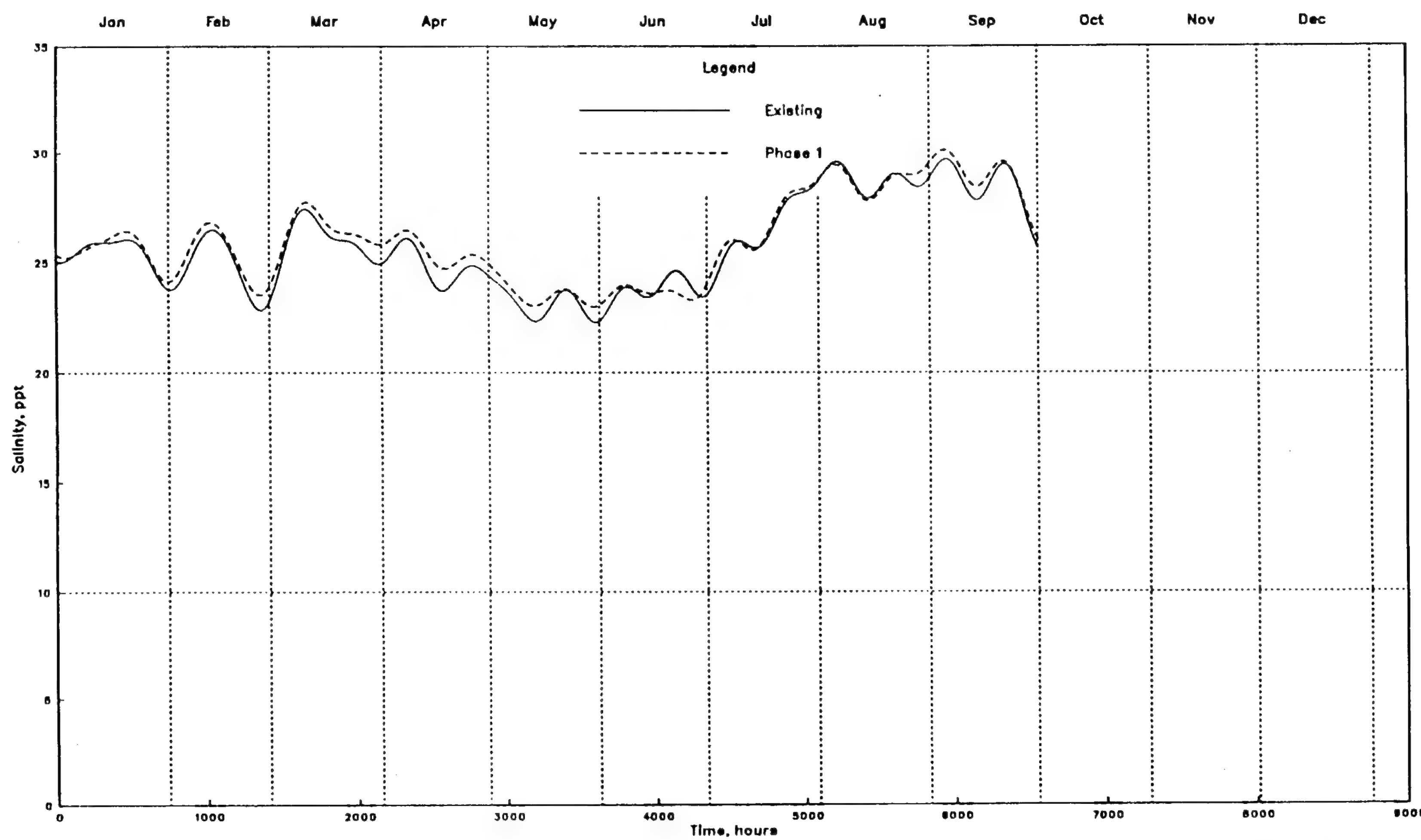
Sep
Oct
Nov
Dec
Time, hours
Salinity, ppt

Plate 116



SALINTY TIME SERIES
2049 LOW FLOW
POINT 5

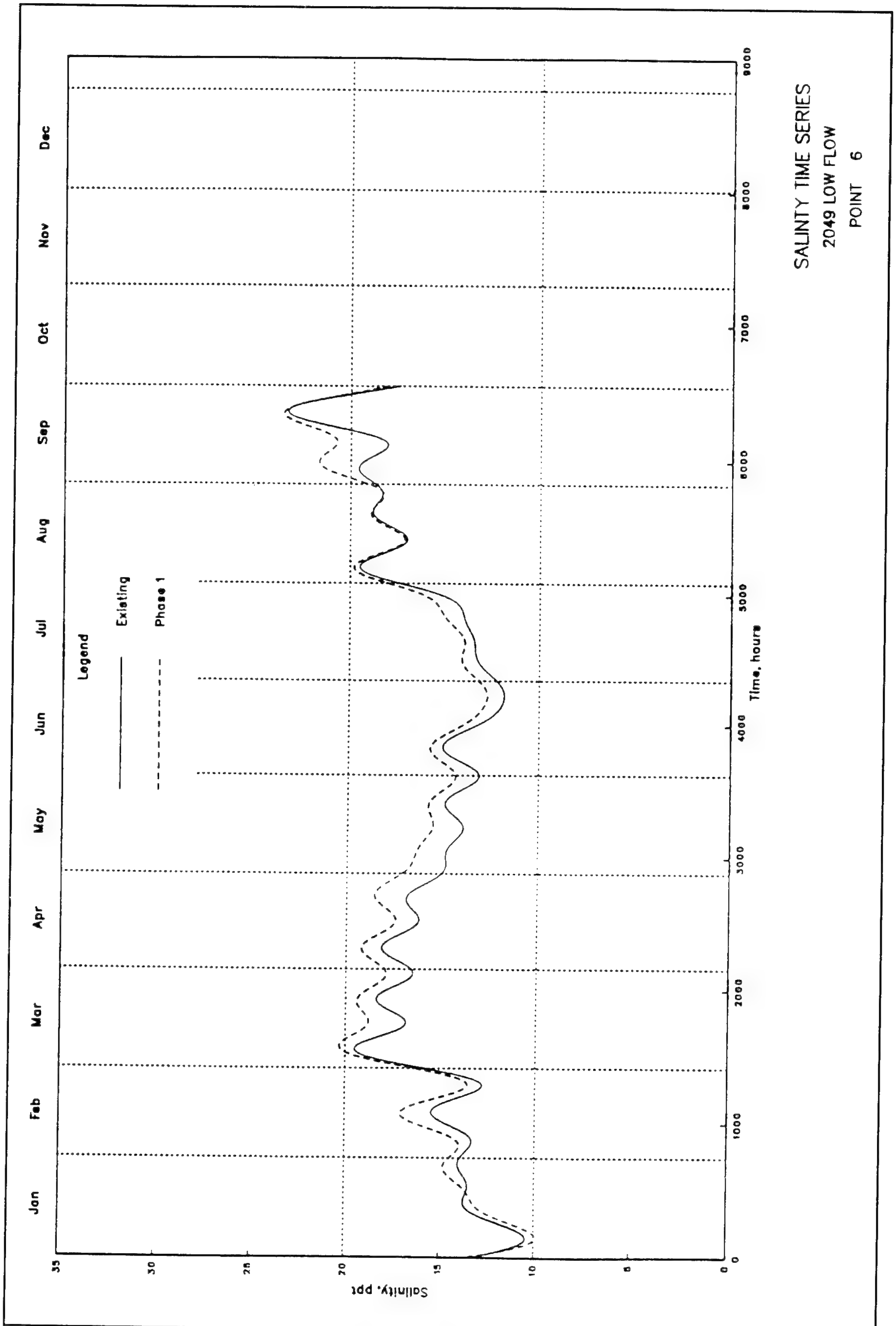

SALINTY TIME SERIES
2049 LOW FLOW
POINT 6
Legend
Existing
Phase 1
Time, hours
Salinity, ppt
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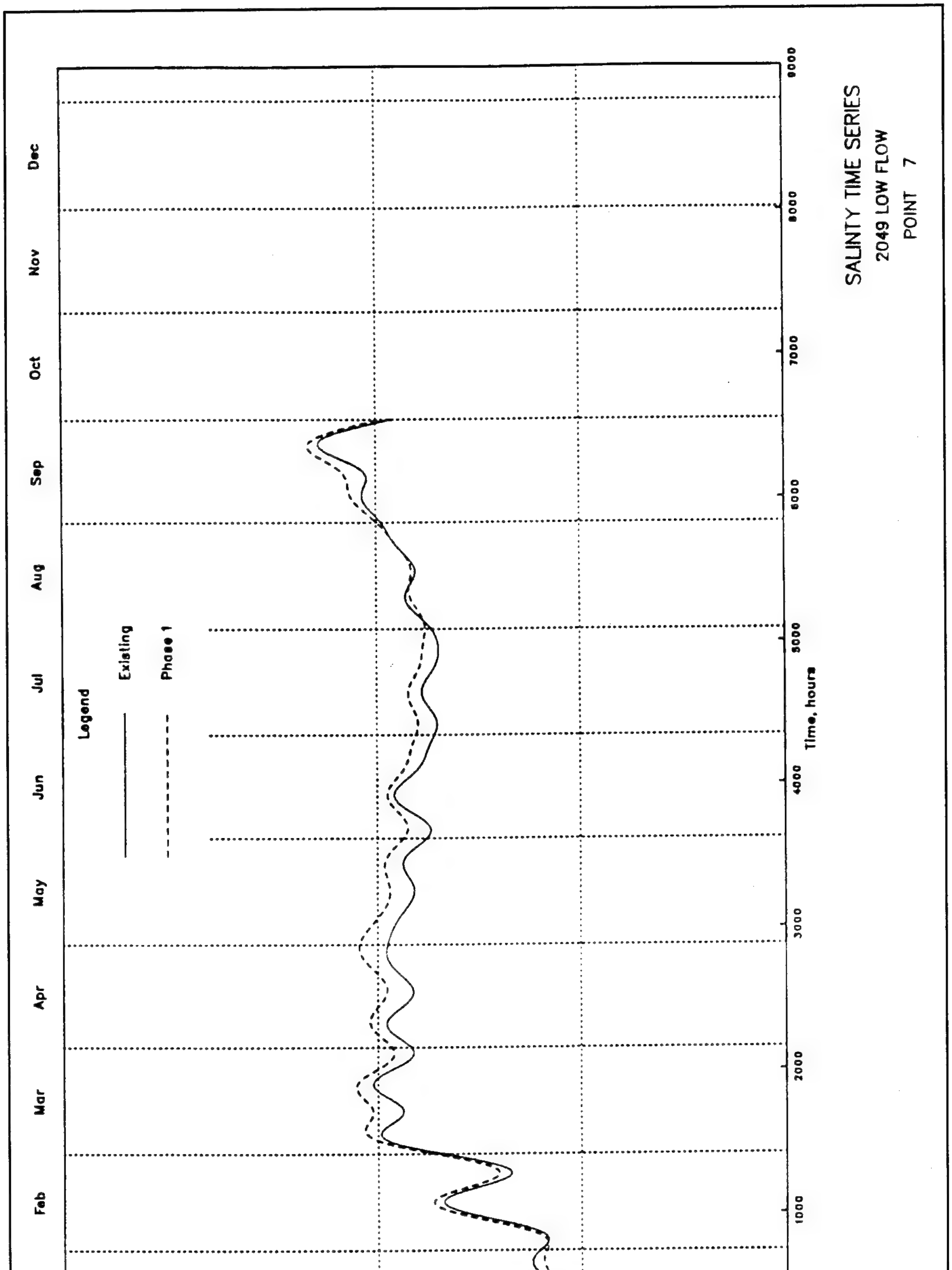
Plate 118



SALINTY TIME SERIES
2049 LOW FLOW
POINT 7
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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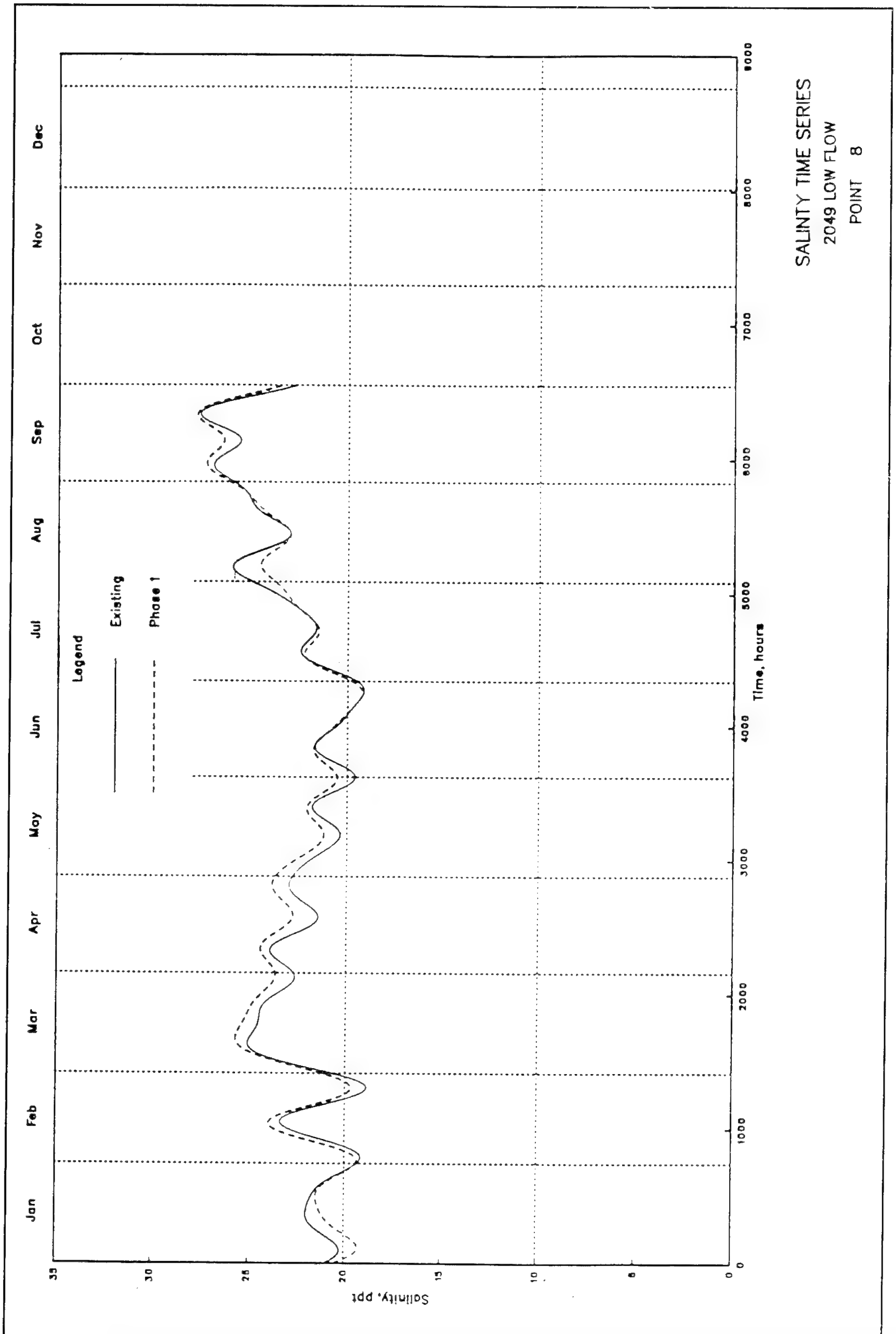

SALINTY TIME SERIES
2049 LOW FLOW
POINT 8
Legend
Existing
Phase 1
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Salinity, ppt
Time, hours
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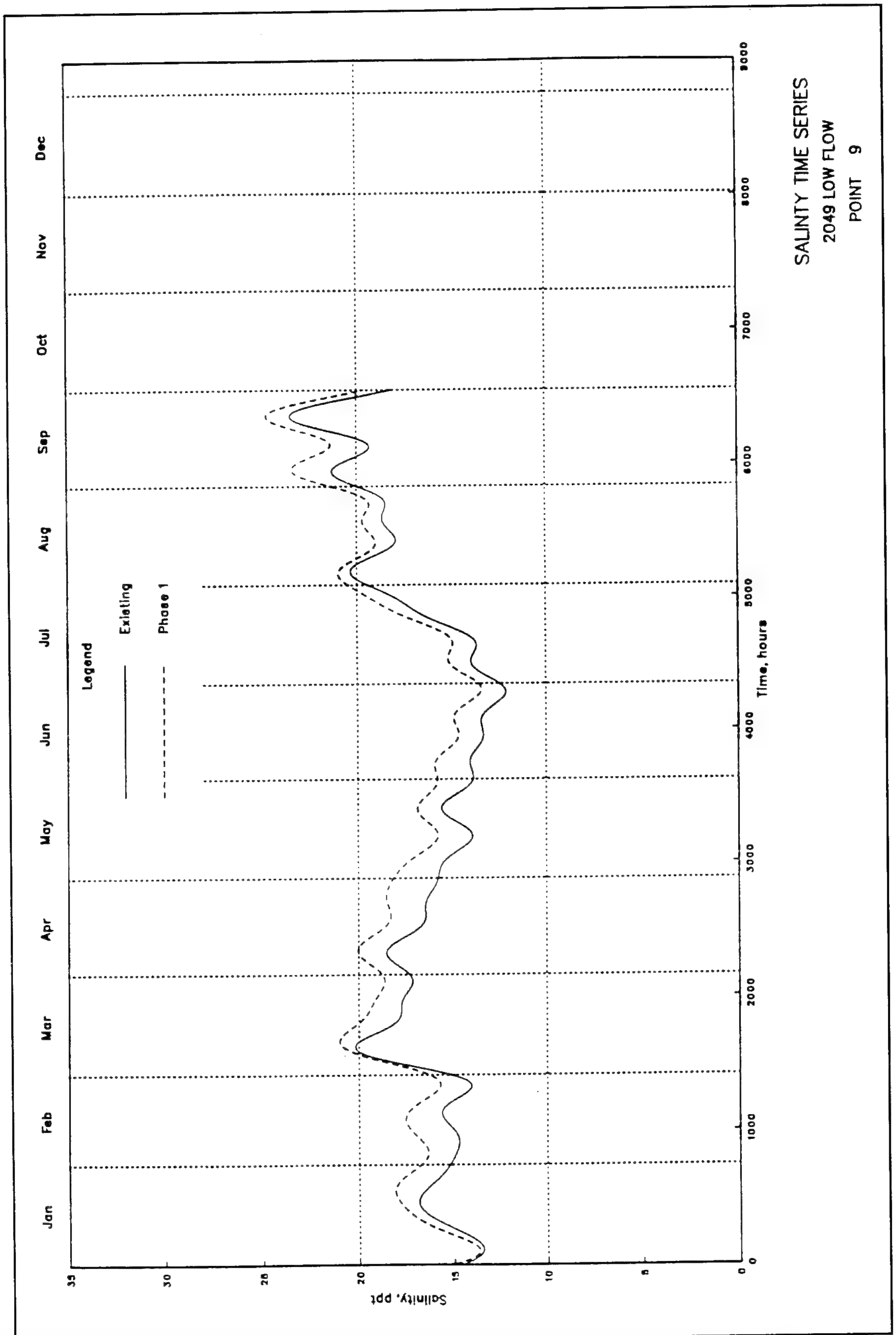
SALINTY TIME SERIES
2049 LOW FLOW
POINT 9
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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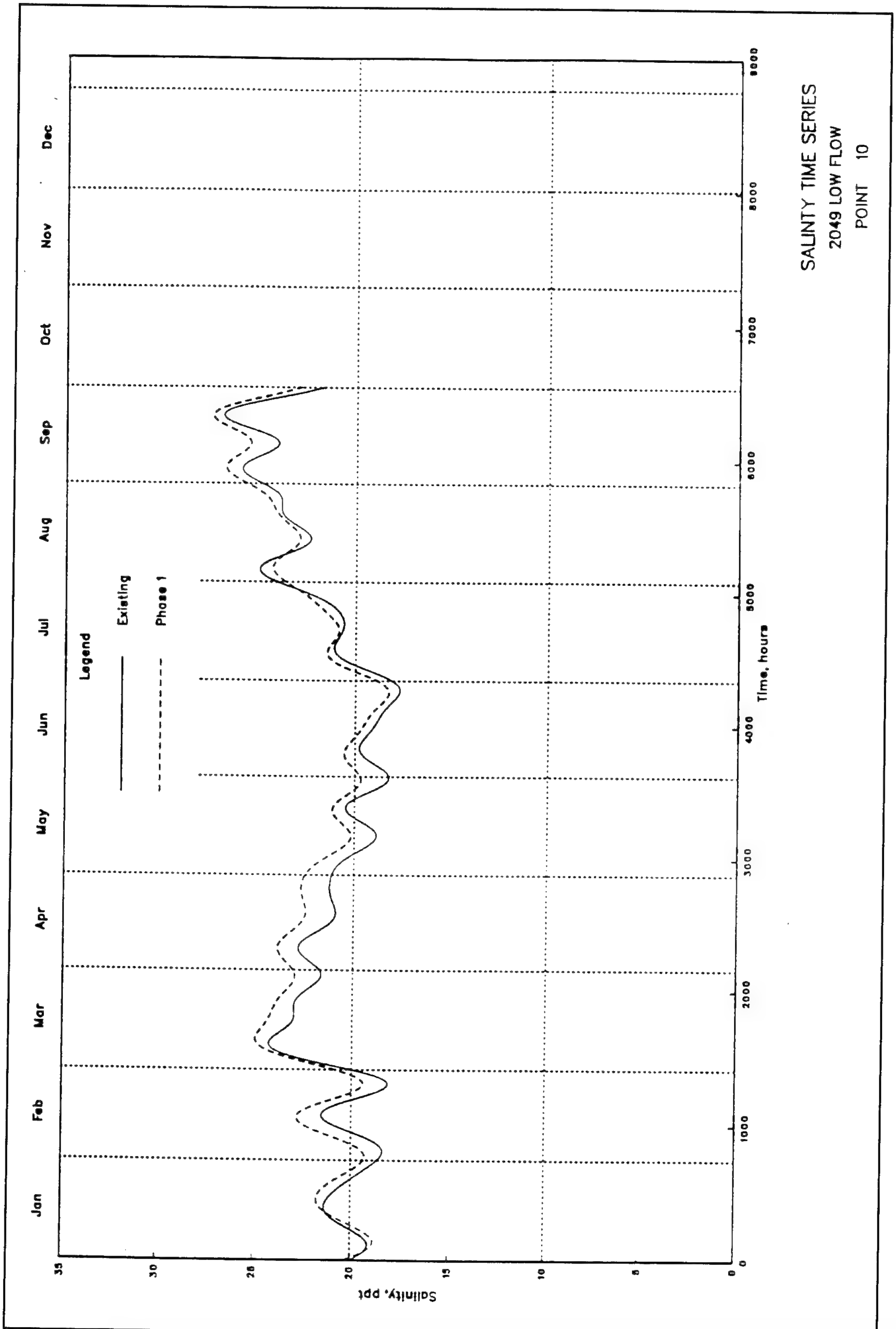
SALINTY TIME SERIES
2049 LOW FLOW
POINT 10
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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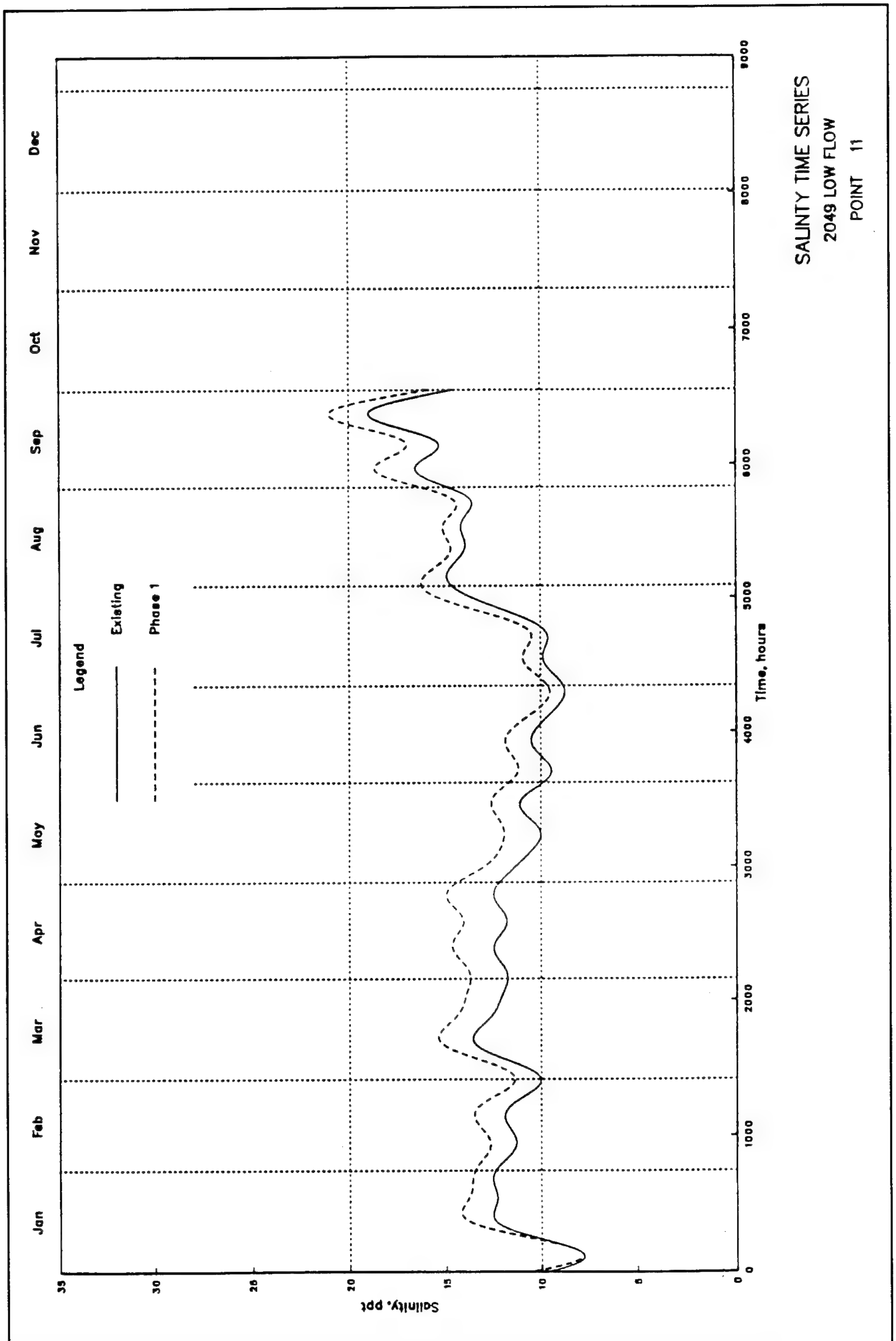
SALINTY TIME SERIES
2049 LOW FLOW
POINT 11
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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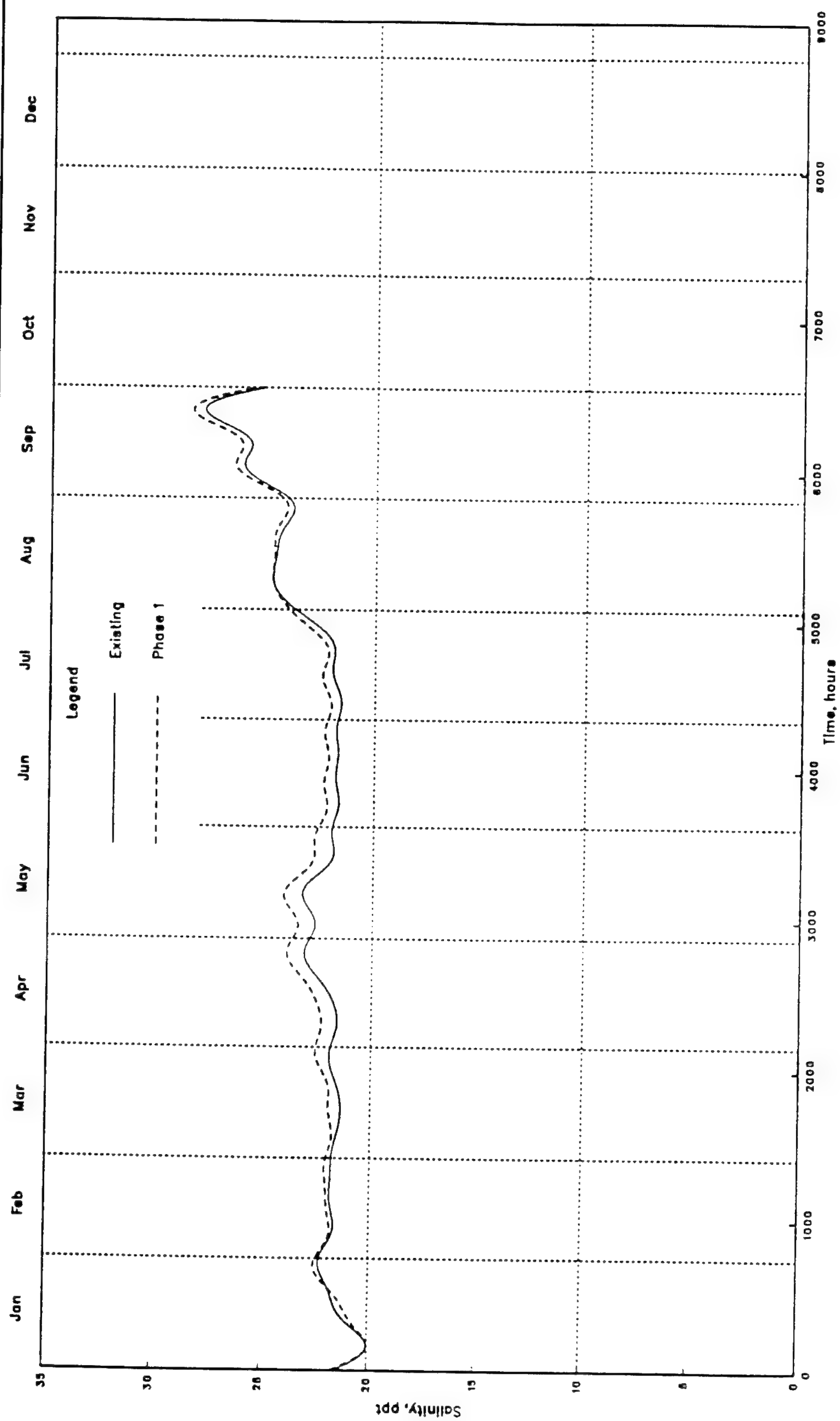
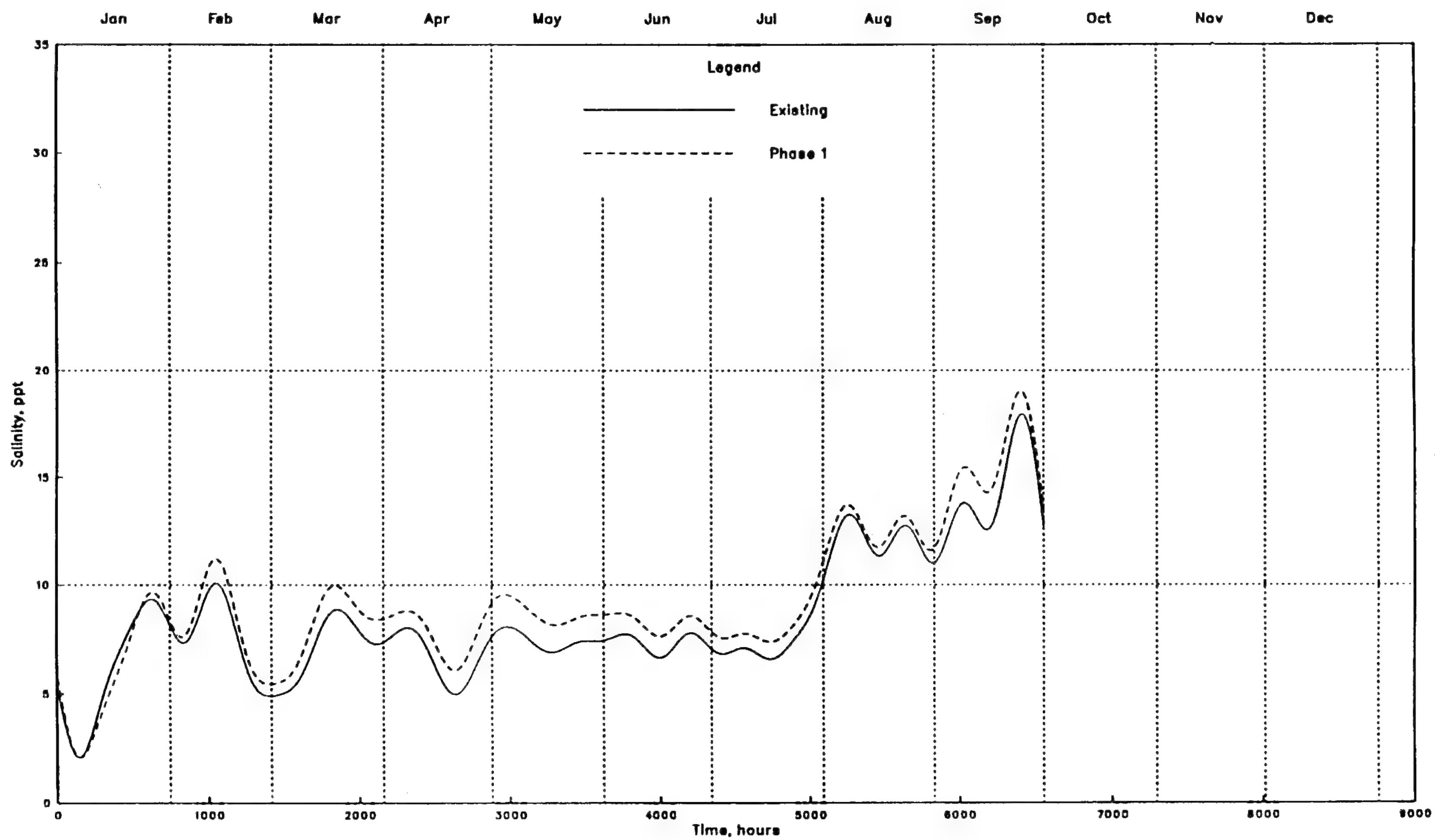


SALINTY TIME SERIES
2049 LOW FLOW
POINT 12

Plate 124



SALINTY TIME SERIES
2049 LOW FLOW
POINT 13

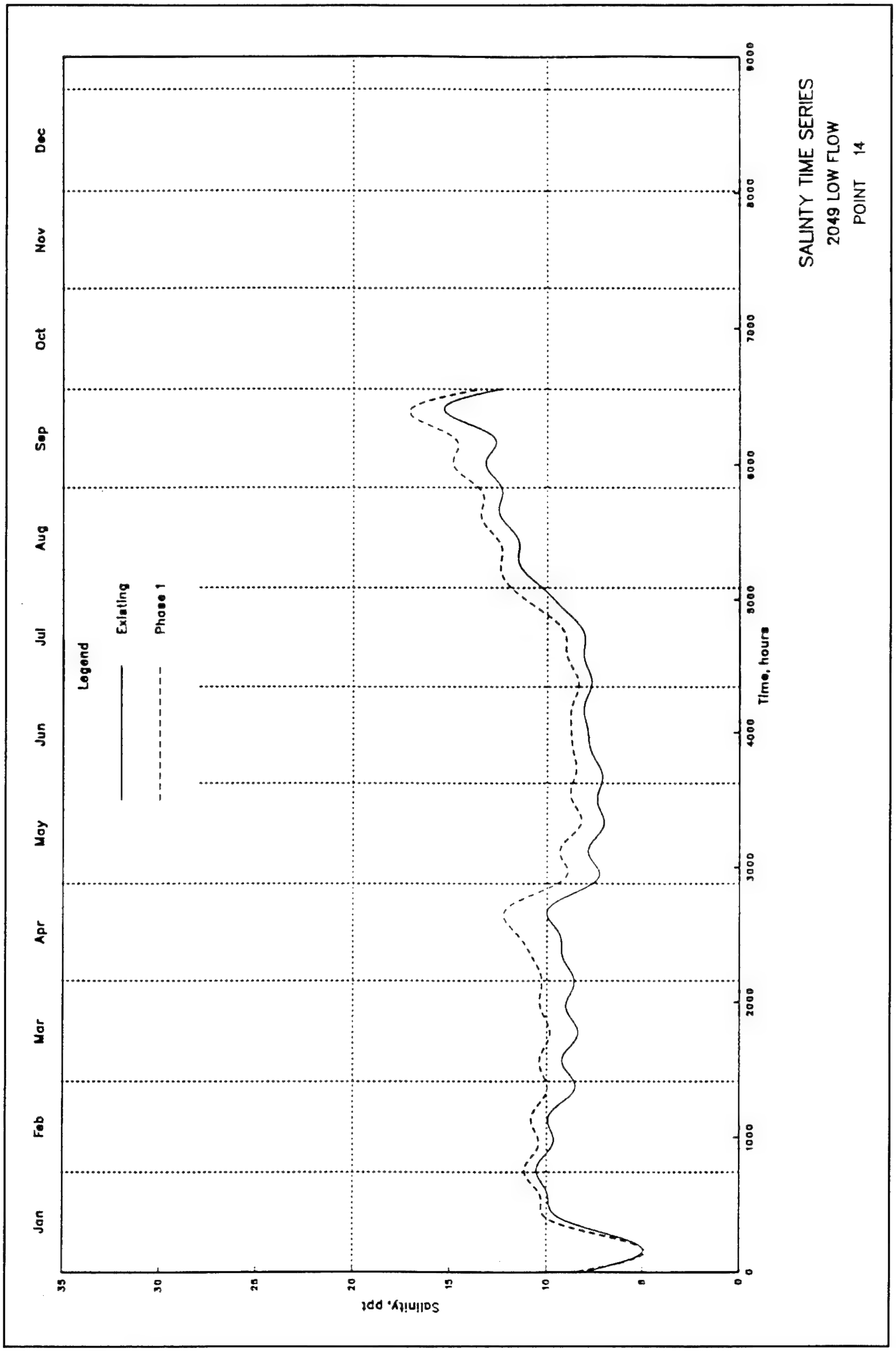

SALINTY TIME SERIES
2049 LOW FLOW
POINT 14
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
Jan
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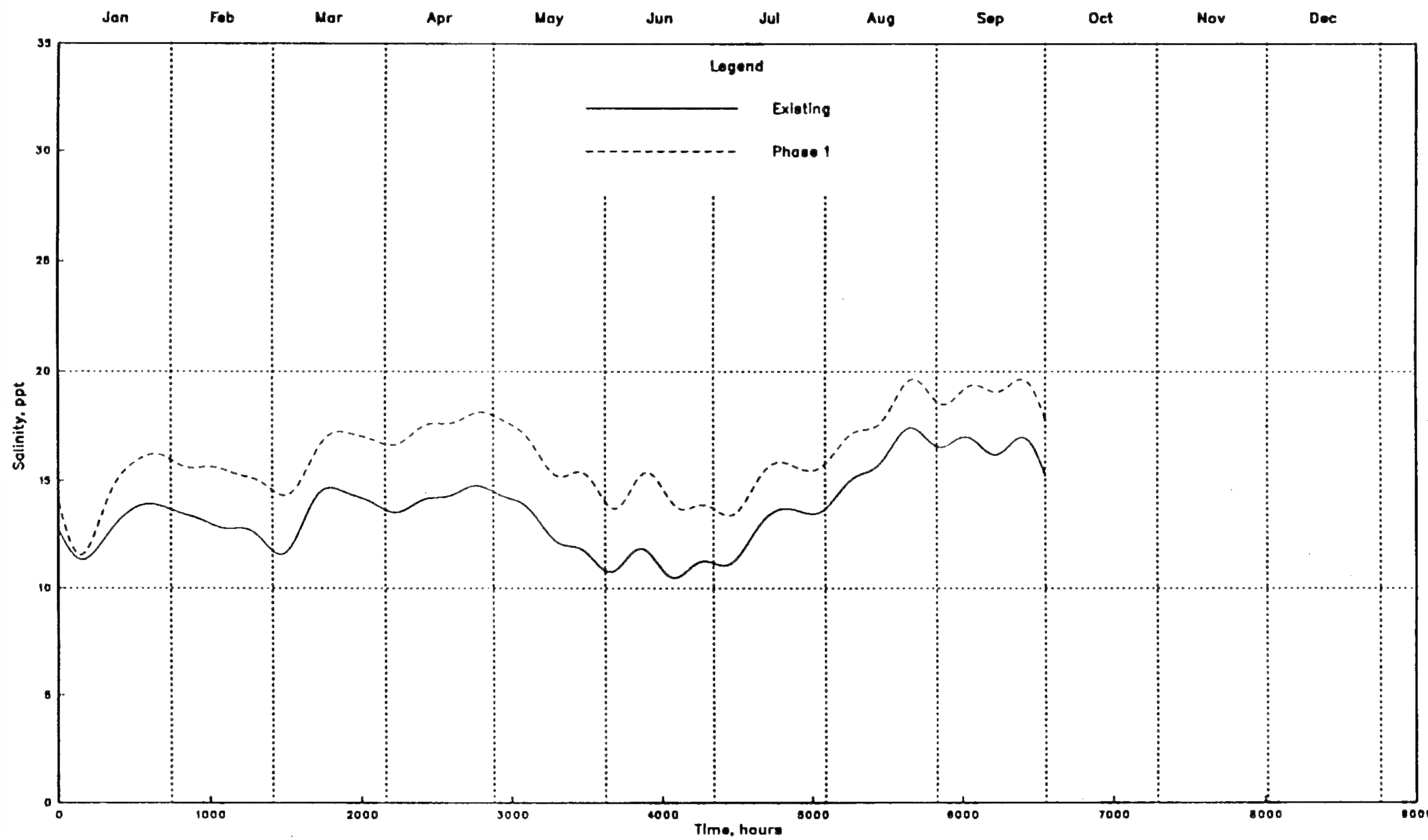
Plate 126



SALINTY TIME SERIES
2049 LOW FLOW
POINT 15

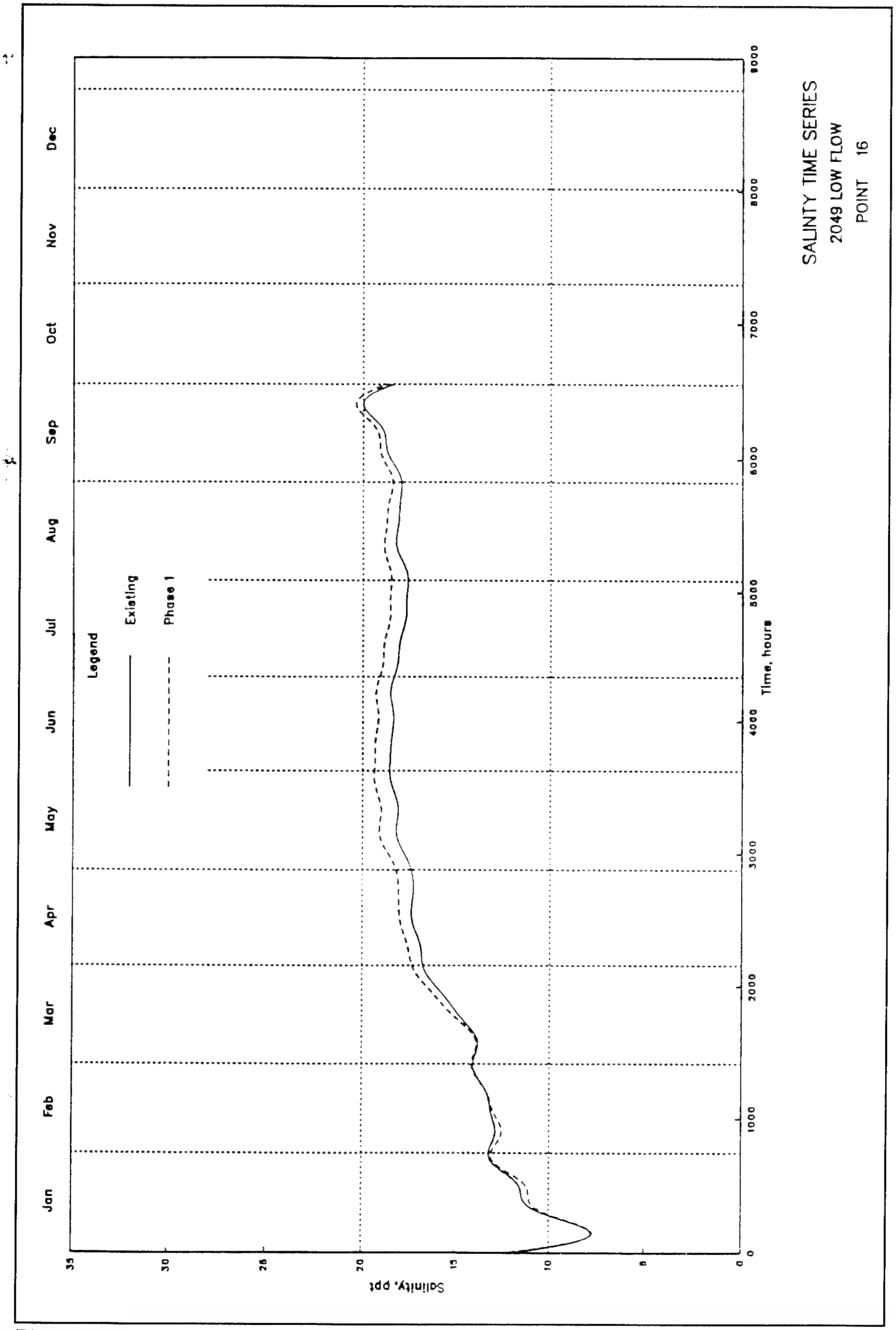

SALINTY TIME SERIES
2049 LOW FLOW
POINT 16
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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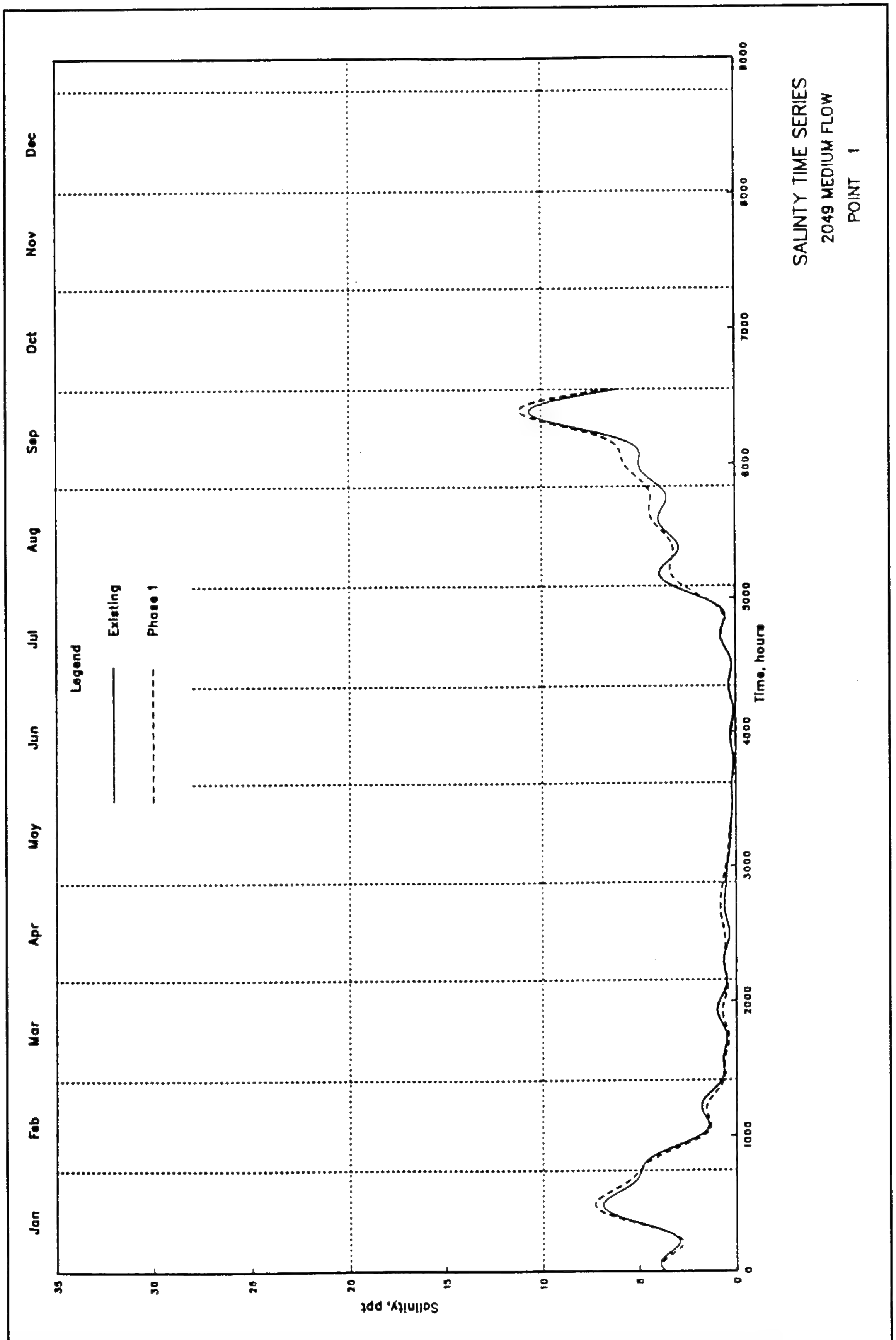
Plate 128


SALINTY TIME SERIES
2049 MEDIUM FLOW
POINT 1
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
Jan
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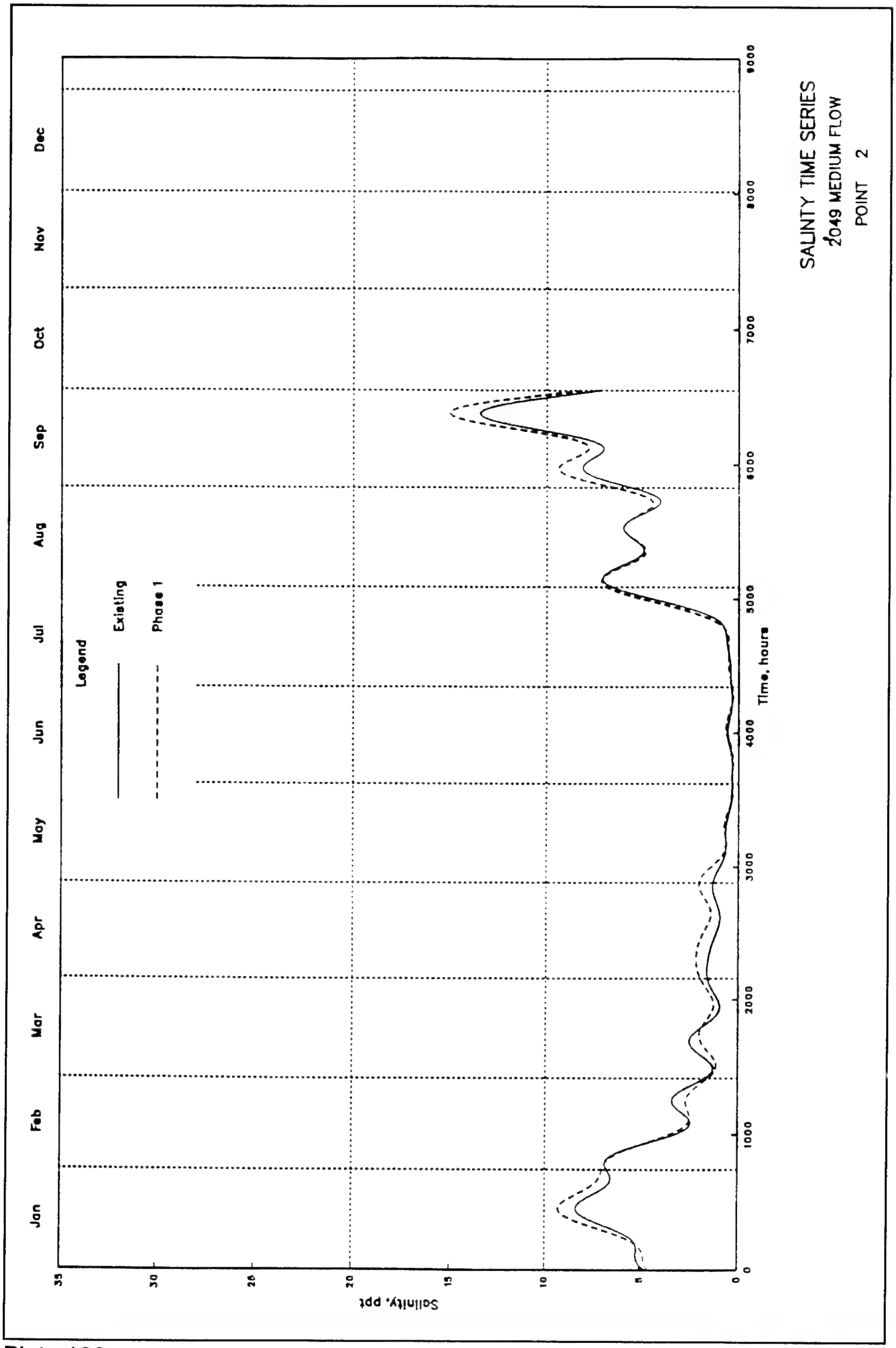
SALINTY TIME SERIES
2049 MEDIUM FLOW
POINT 2
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
Jan
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Plate 130

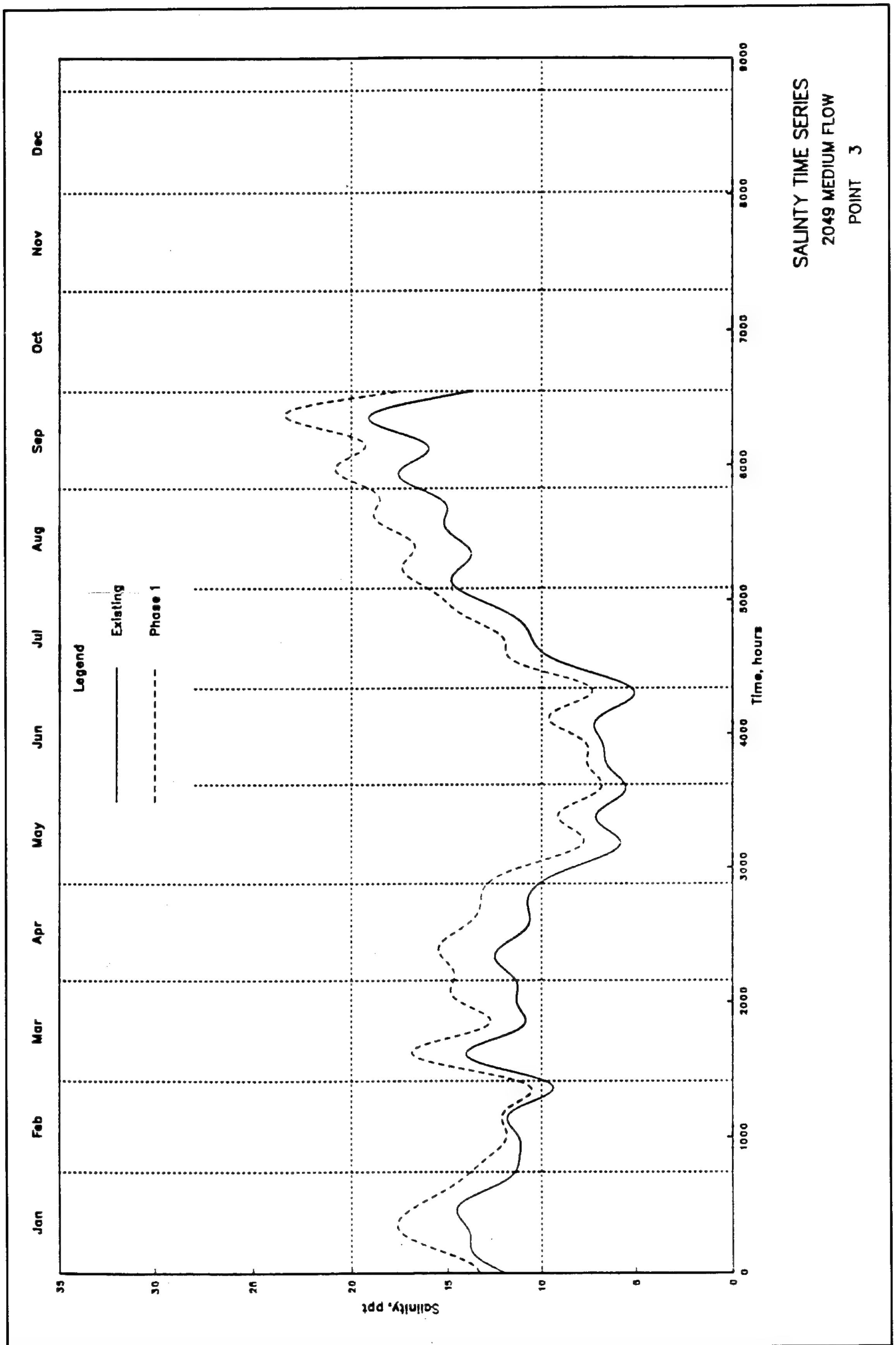
SALINTY TIME SERIES
2049 MEDIUM FLOW
POINT 3
Legend
Existing
Phase 1
Time, hours
Salinity, ppt
Jan
Feb
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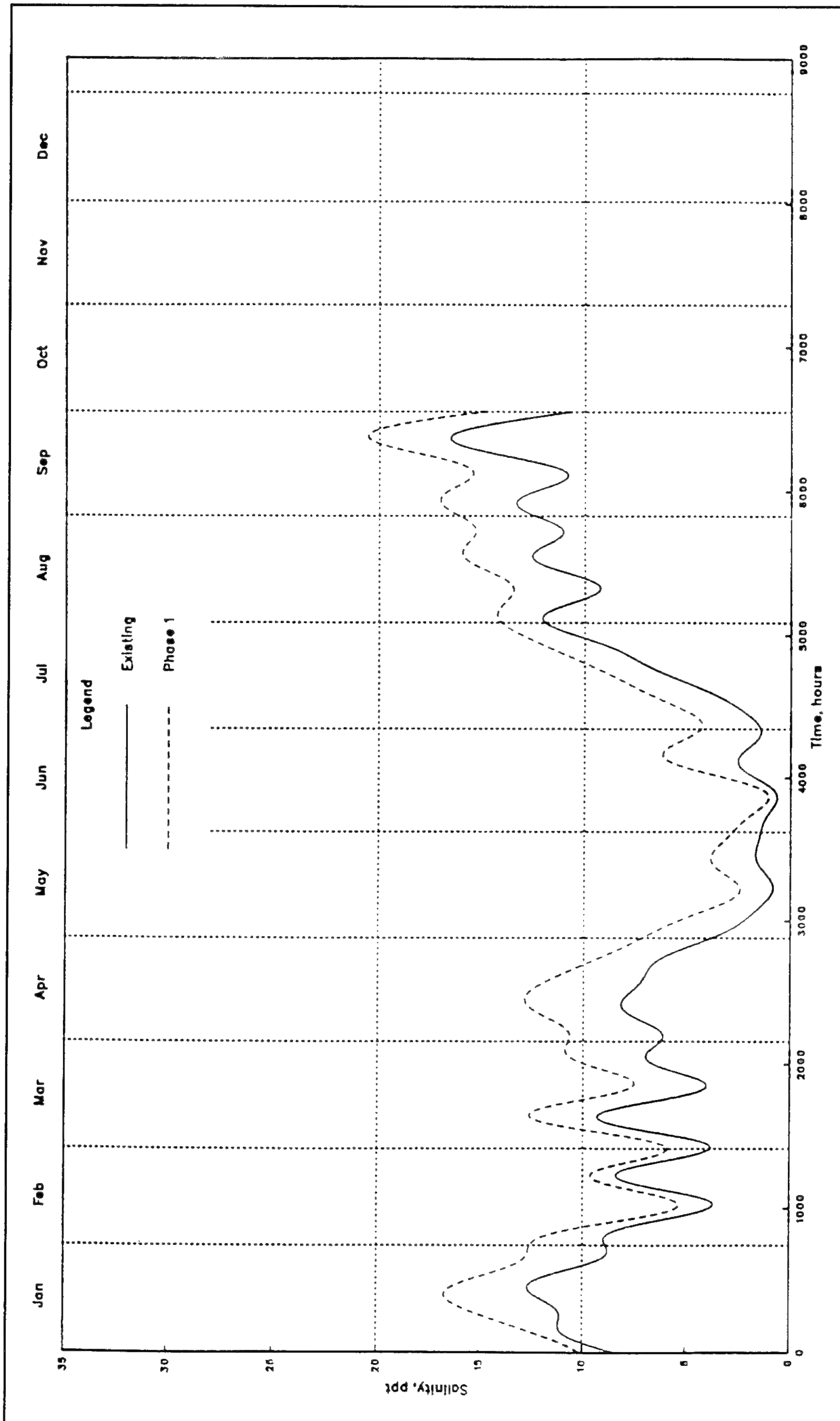
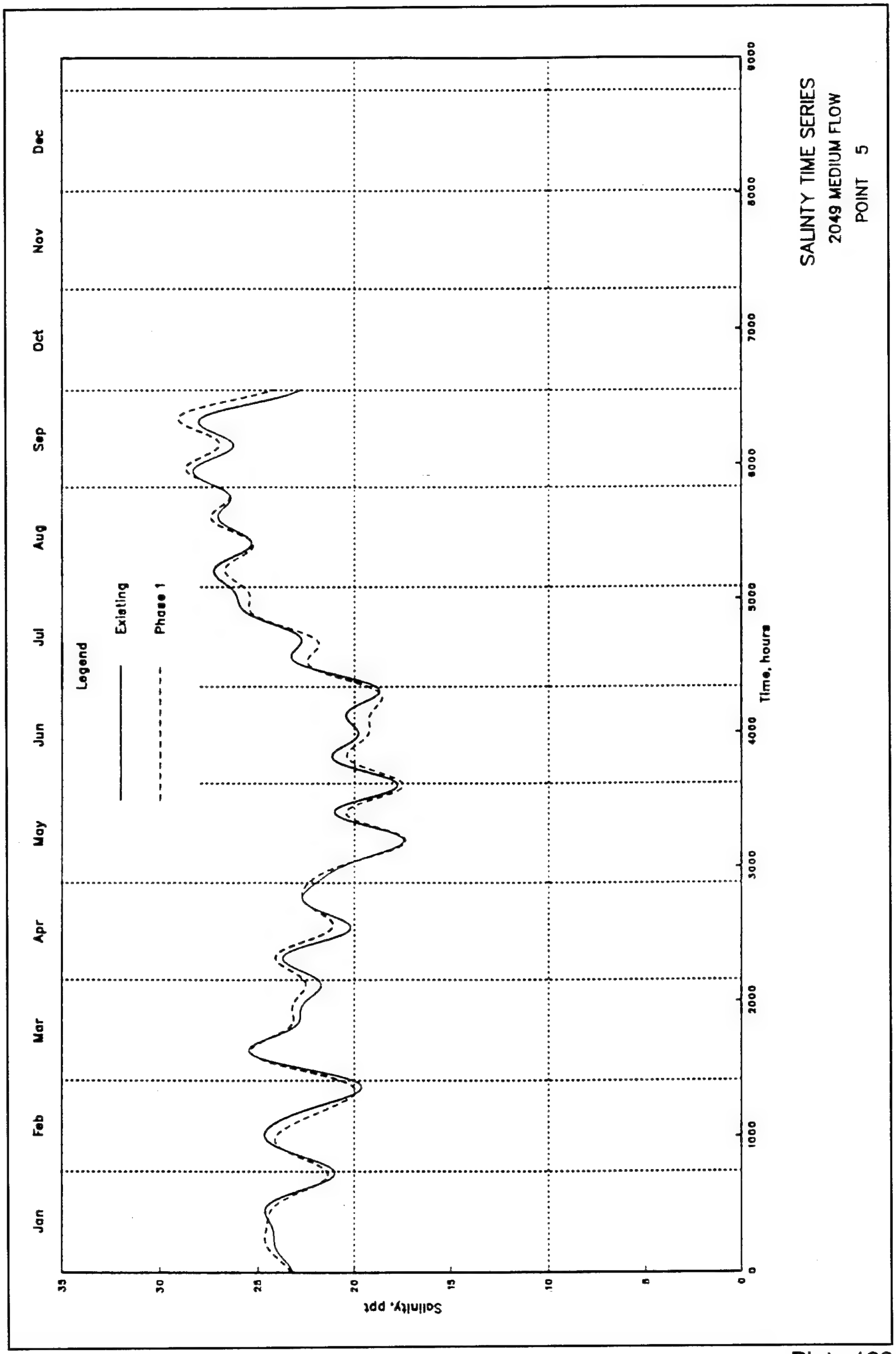
Plate 131



SALINTY TIME SERIES
2049 MEDIUM FLOW
POINT 4



SALINTY TIME SERIES
2049 MEDIUM FLOW
POINT 5
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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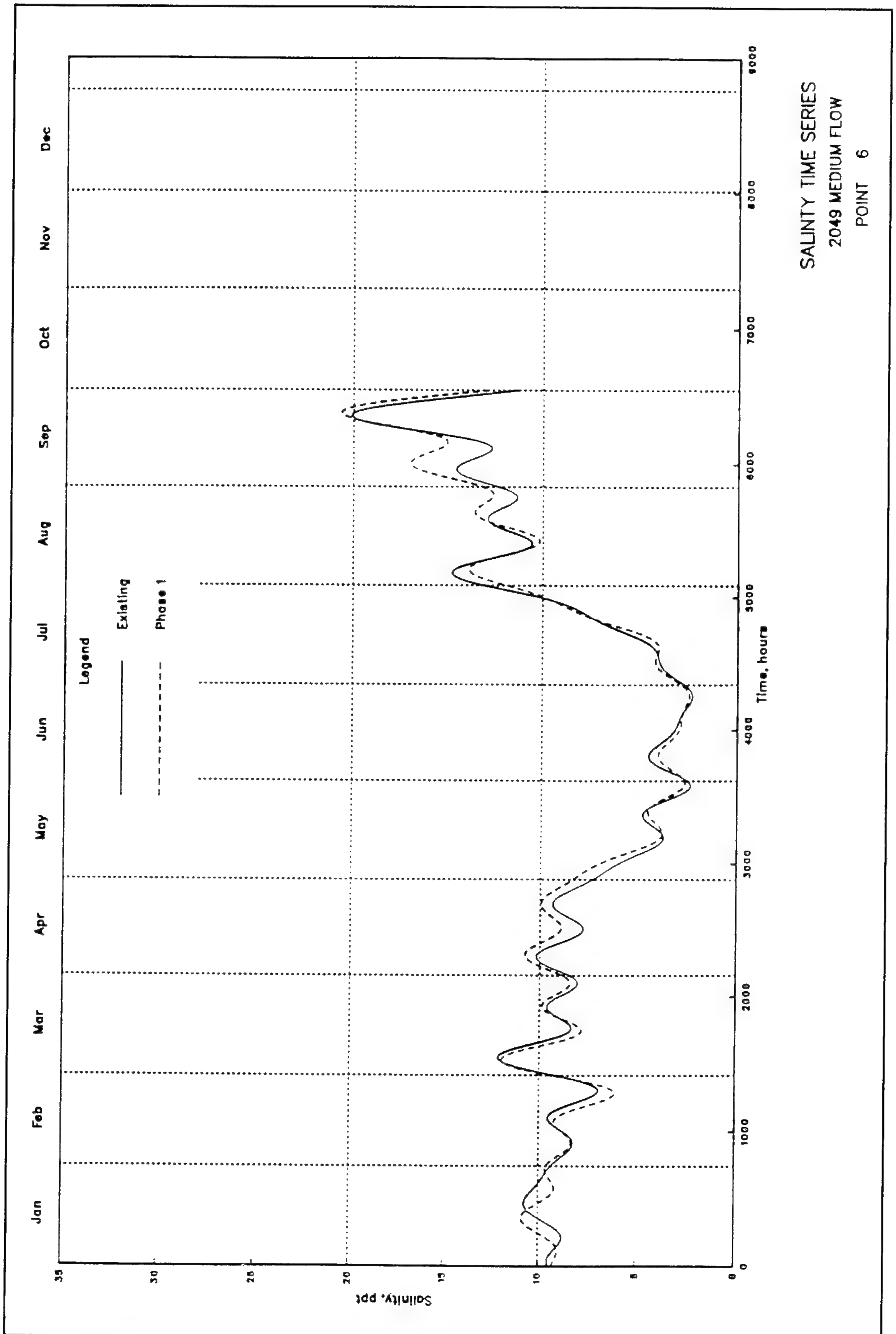
Plate 133


SALINTY TIME SERIES
2049 MEDIUM FLOW
POINT 6
Legend
Existing
Phase 1
Jan
Feb
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Salinity, ppt
Time, hours
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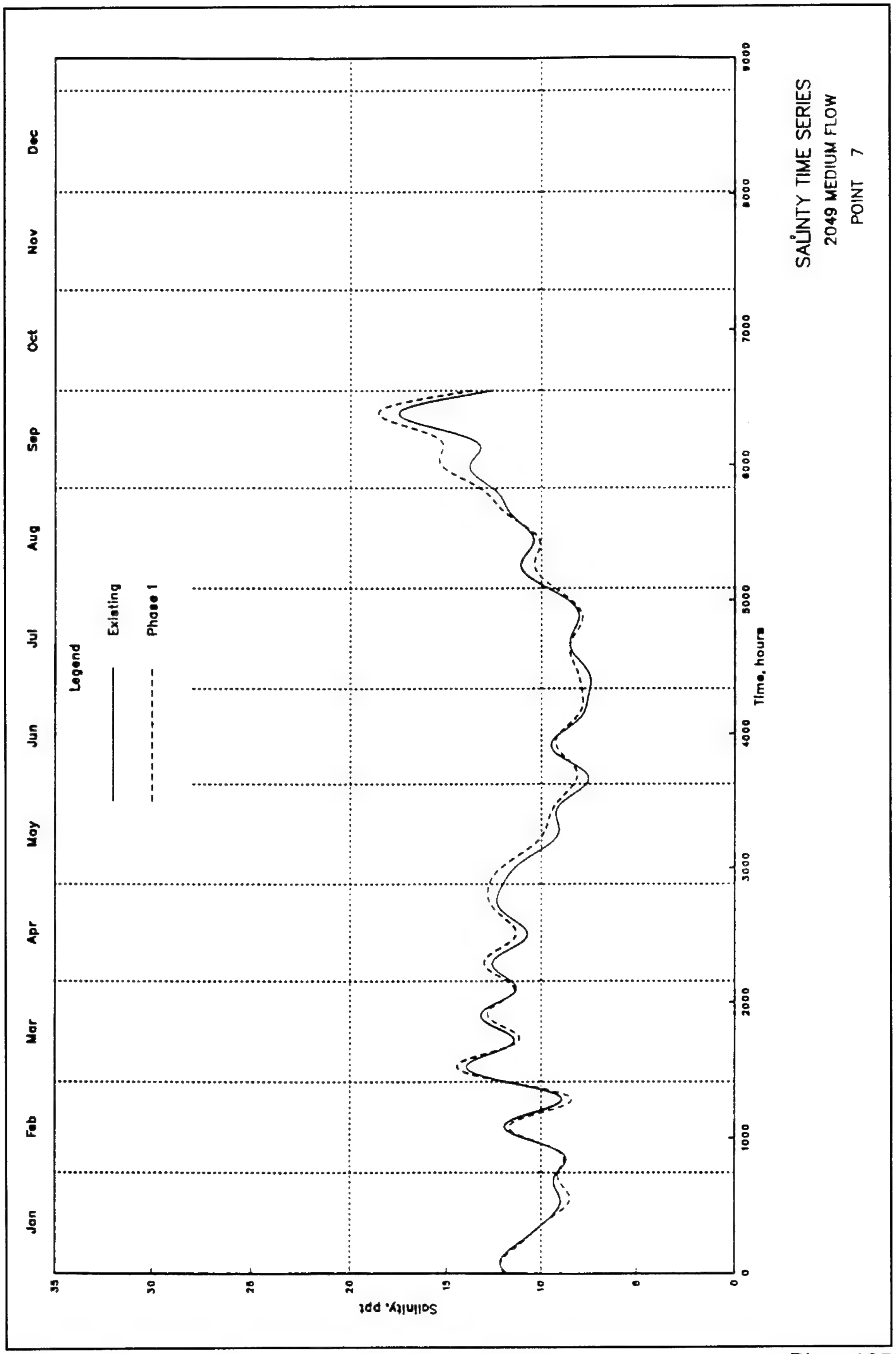
Plate 134



SALINTY TIME SERIES
2049 MEDIUM FLOW
POINT 7
Legend
Existing
Phase 1
Jan
Feb
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Salinity, ppt
Time, hours
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Plate 135

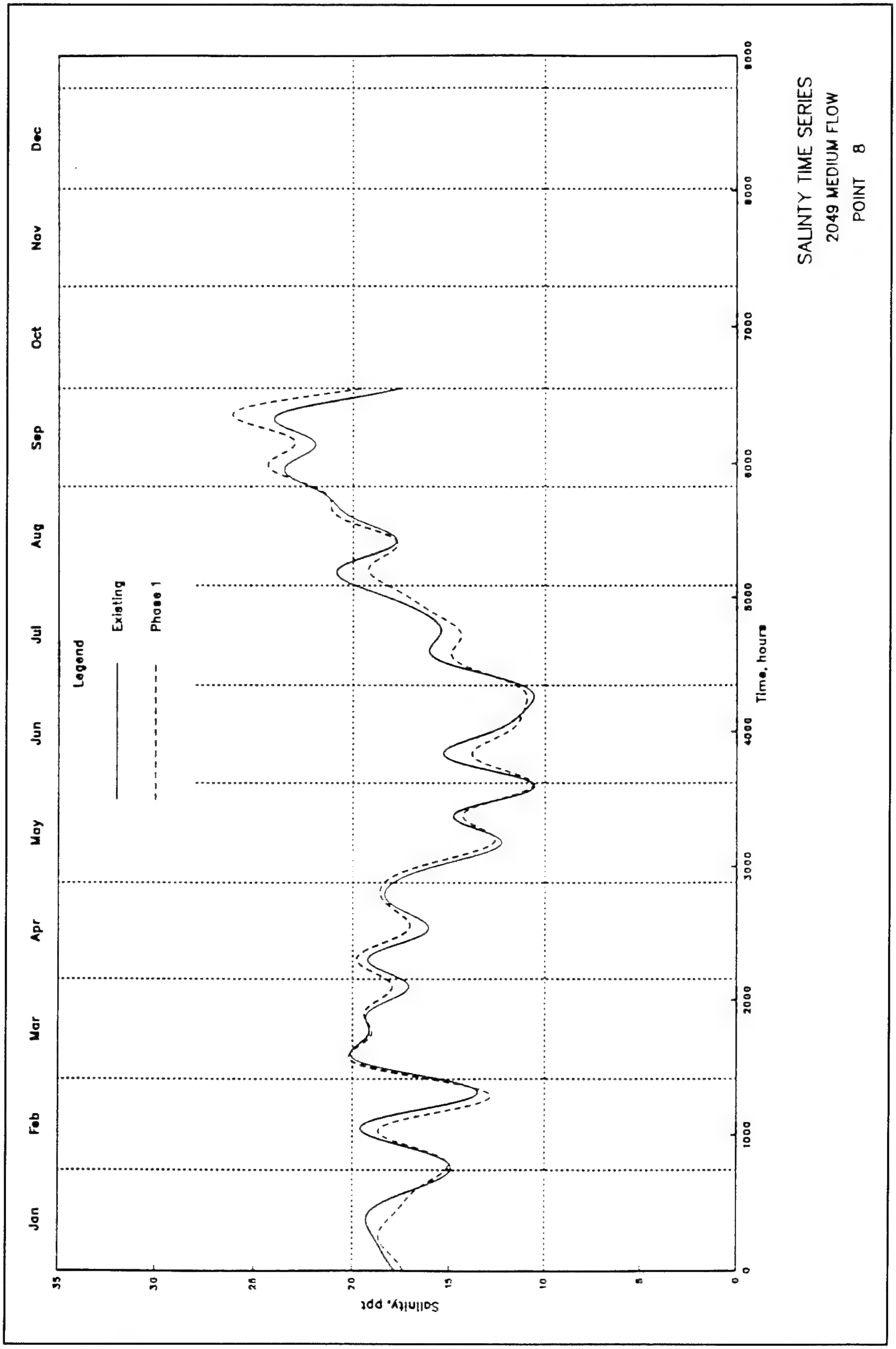
SALINTY TIME SERIES
2049 MEDIUM FLOW
POINT 8
Legend
Existing
Phase 1
Time, hours
Salinity, ppt
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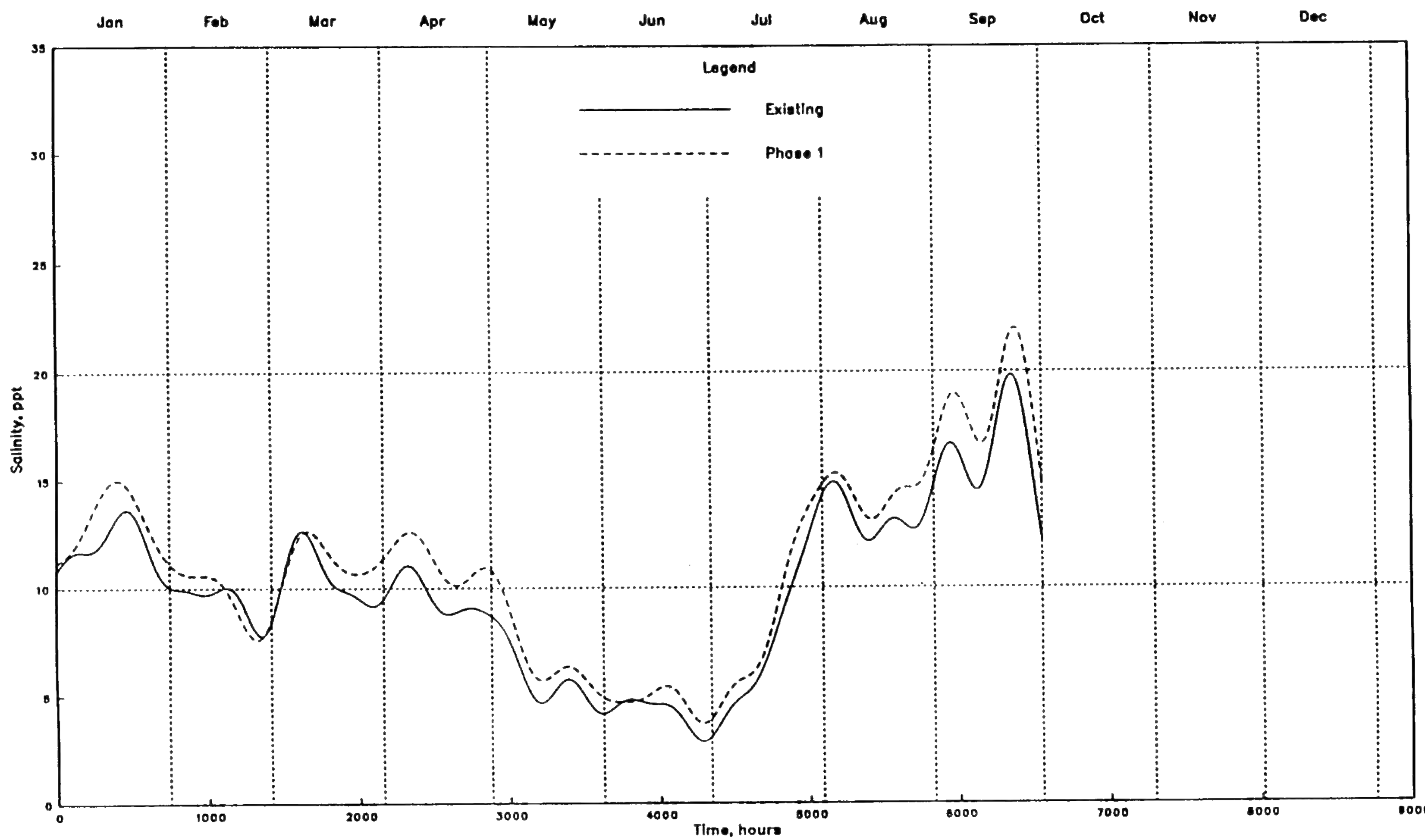
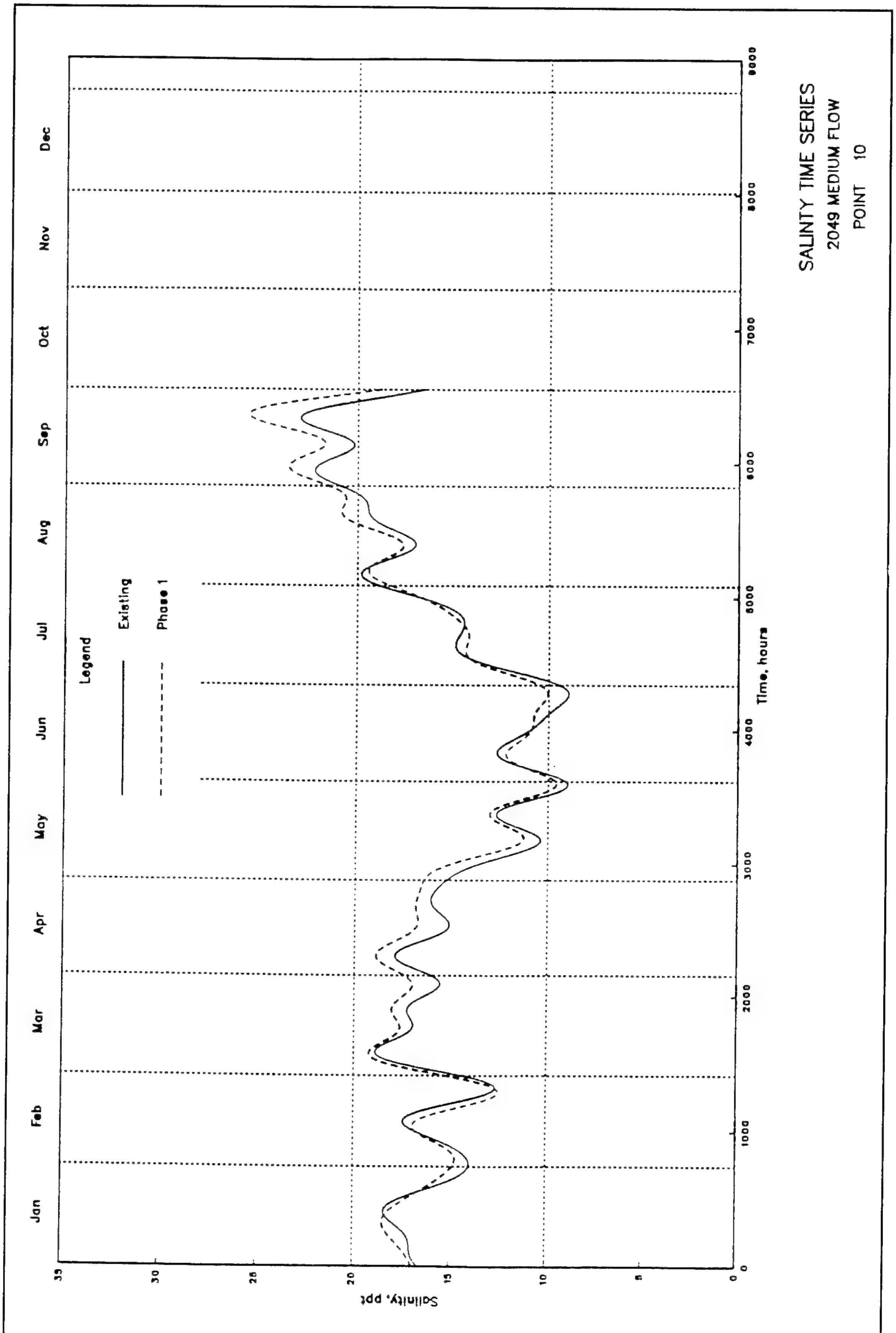
Plate 136



SALINTY TIME SERIES
2049 MEDIUM FLOW
POINT 9


SALINTY TIME SERIES
2049 MEDIUM FLOW
POINT 10
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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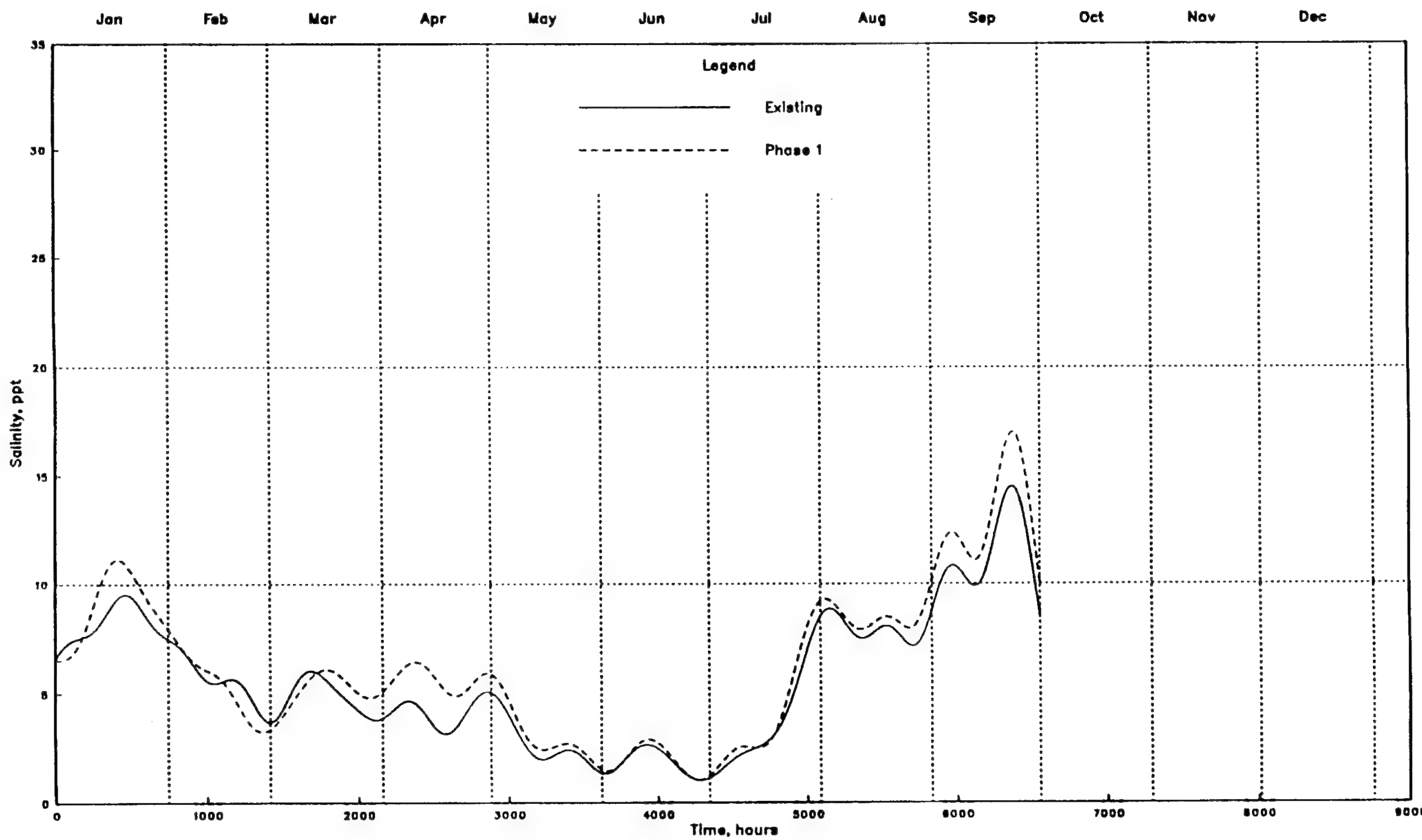
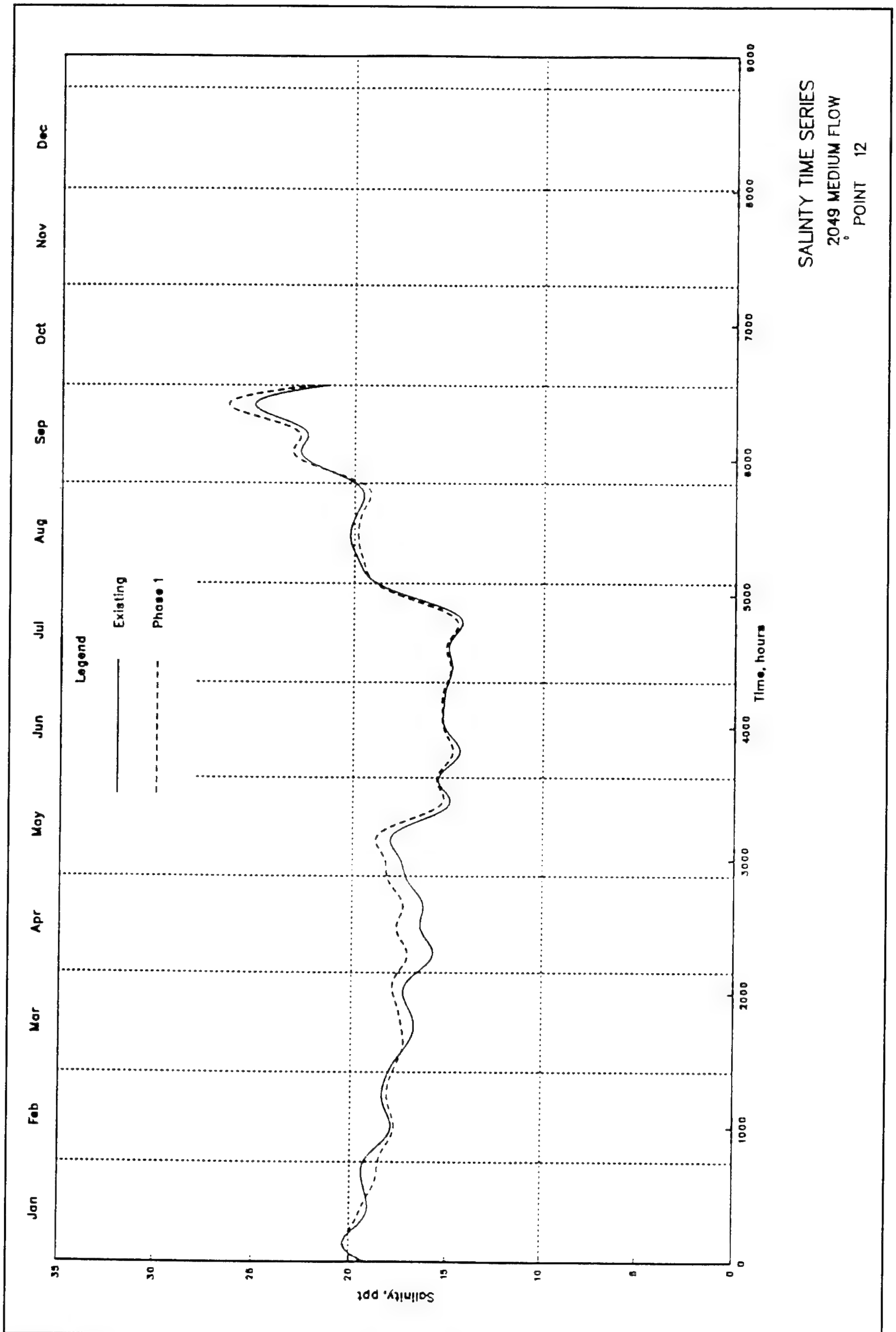
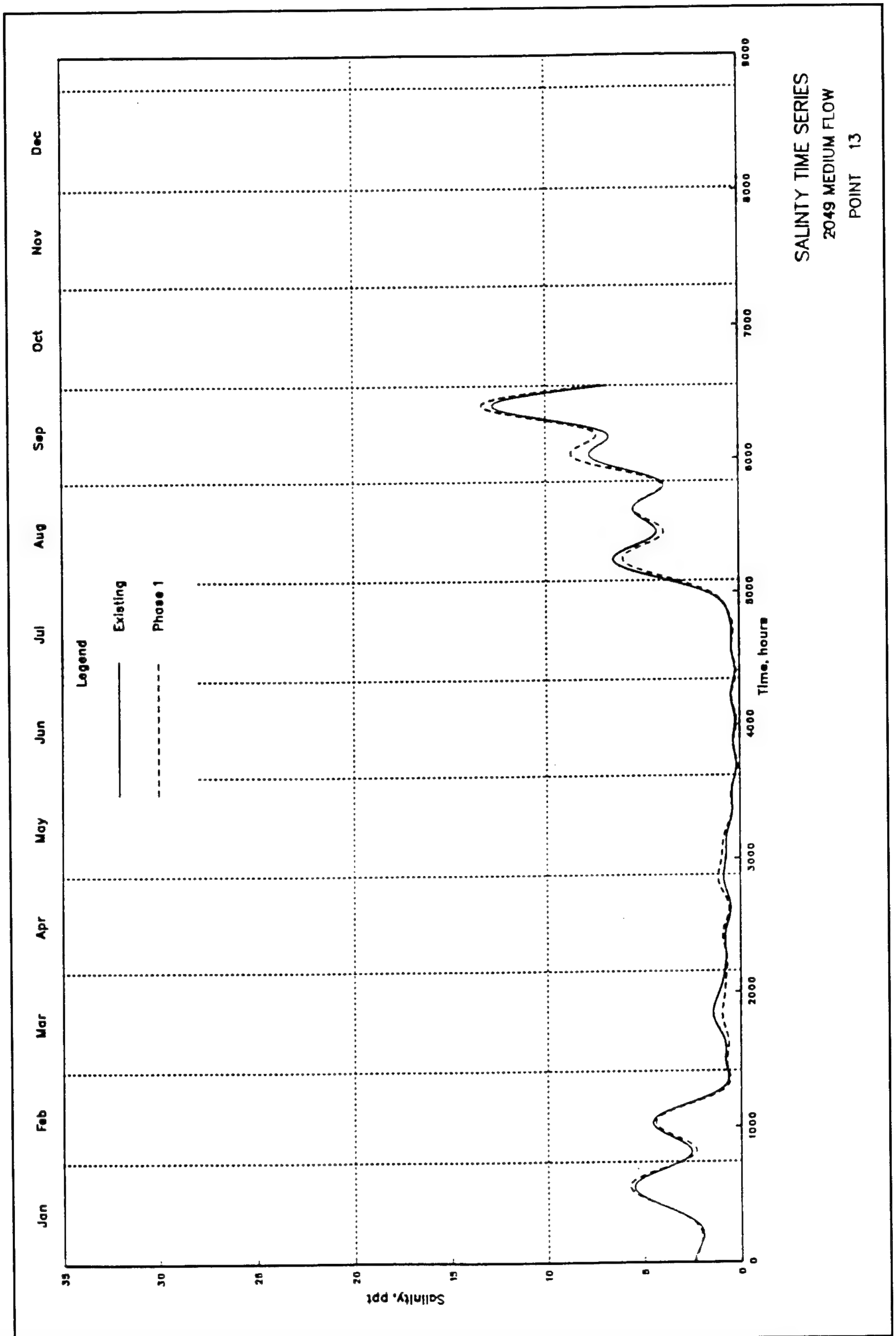


SALINTY TIME SERIES
2049 MEDIUM FLOW
POINT 11



SALINTY TIME SERIES
2049 MEDIUM FLOW
POINT 12

Plate 140



SALINTY TIME SERIES
2049 MEDIUM FLOW
POINT 13
Legend
Existing
Phase 1
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Salinity, ppt
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Time, hours
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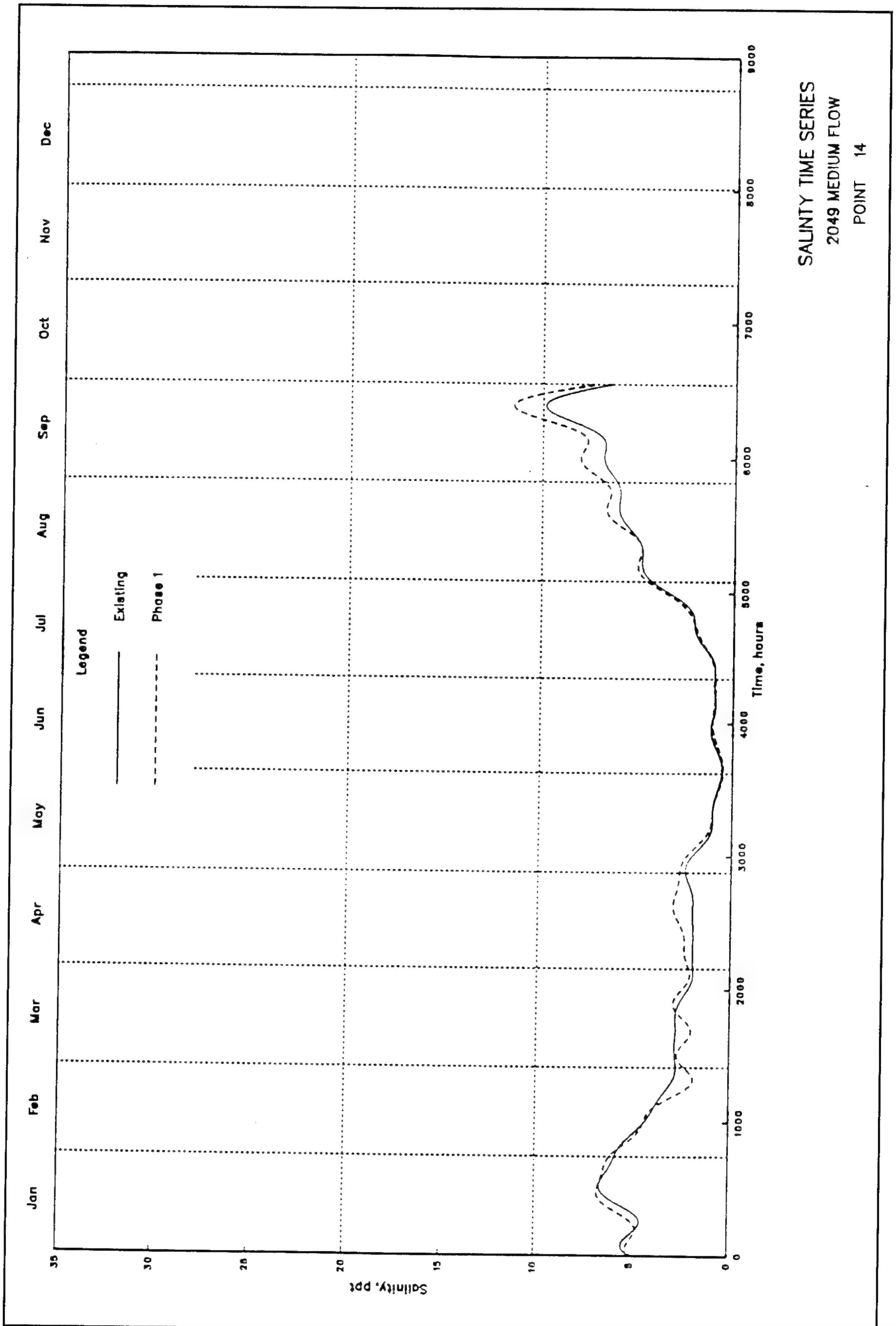
SALINTY TIME SERIES
2049 MEDIUM FLOW
POINT 14
Legend
Existing
Phase 1
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Time, hours
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Salinity, ppt
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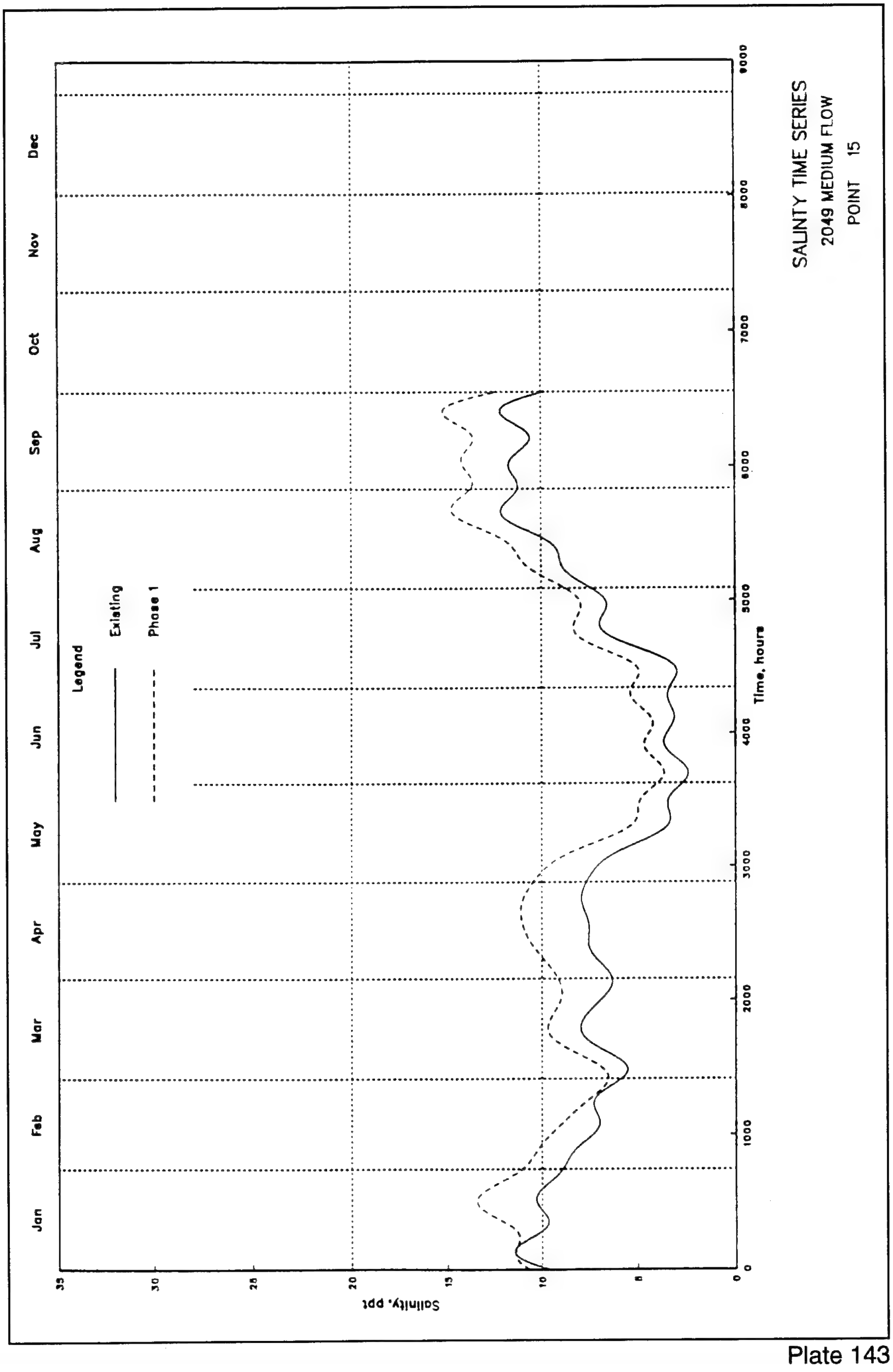
Plate 142



SALINTY TIME SERIES
2049 MEDIUM FLOW
POINT 15
Legend
Existing
Phase 1
Time, hours
Salinity, ppt
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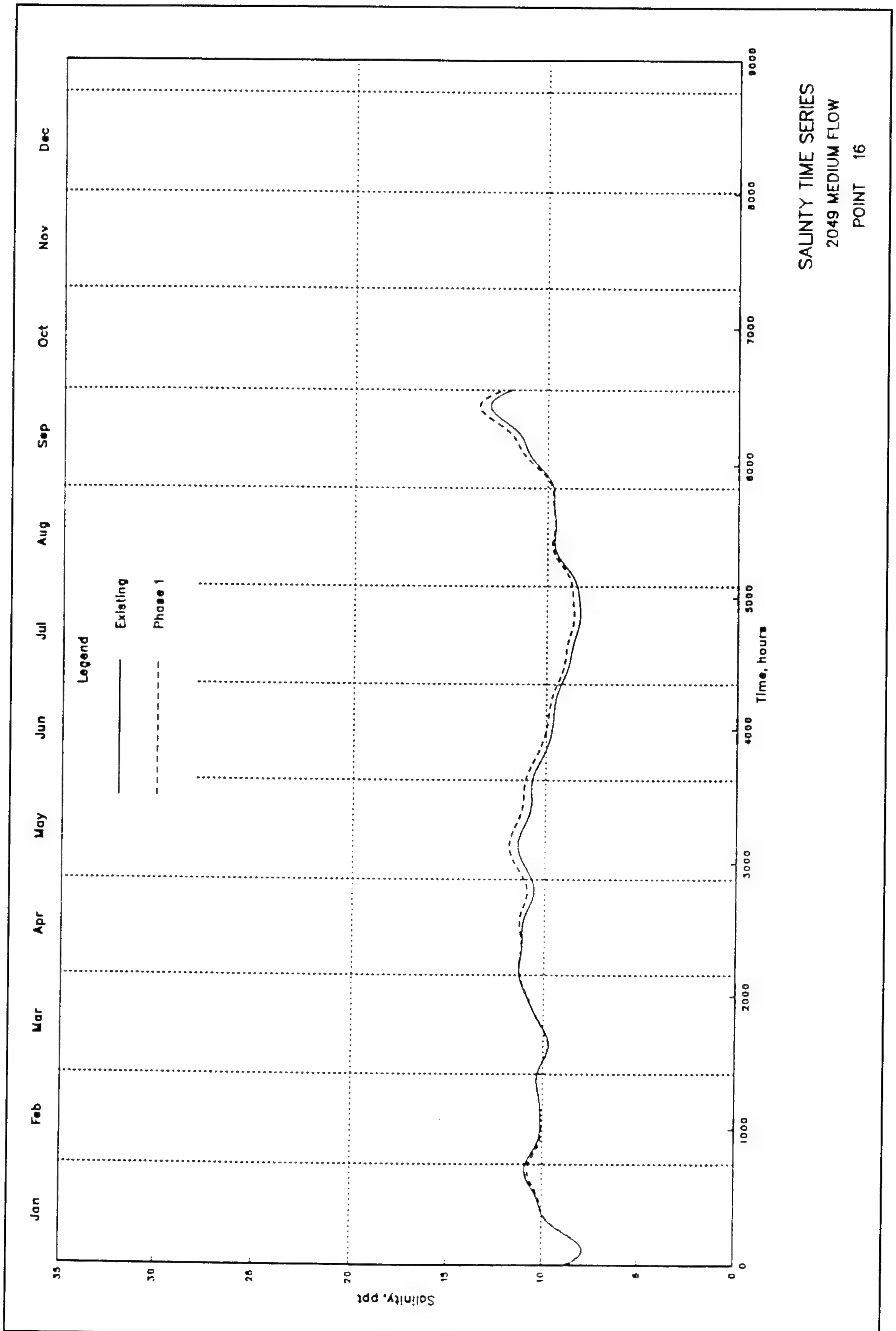
SALINTY TIME SERIES
2049 MEDIUM FLOW
POINT 16
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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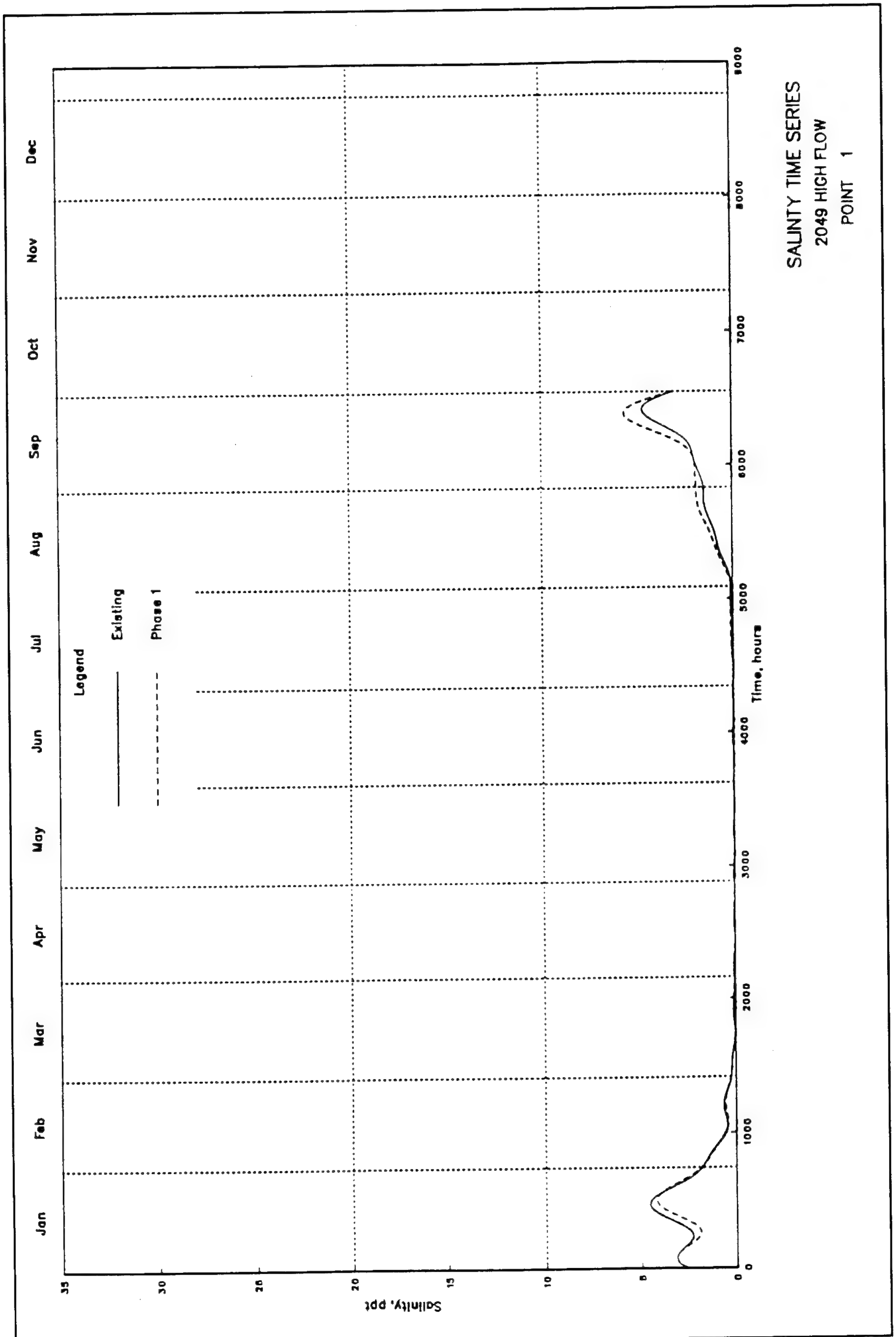
Plate 144


SALINTY TIME SERIES
2049 HIGH FLOW
POINT 1
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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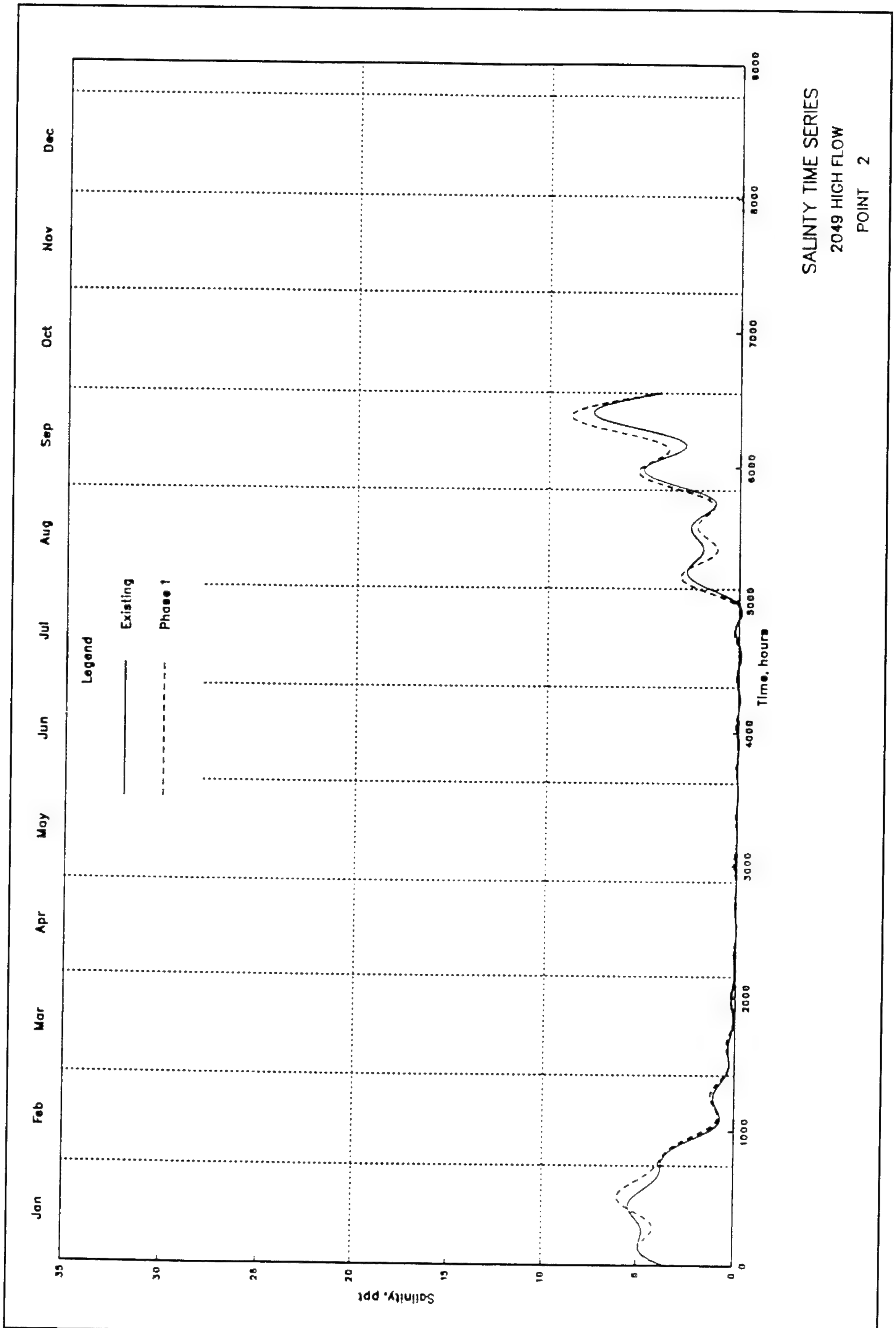
SALINTY TIME SERIES
2049 HIGH FLOW
POINT 2
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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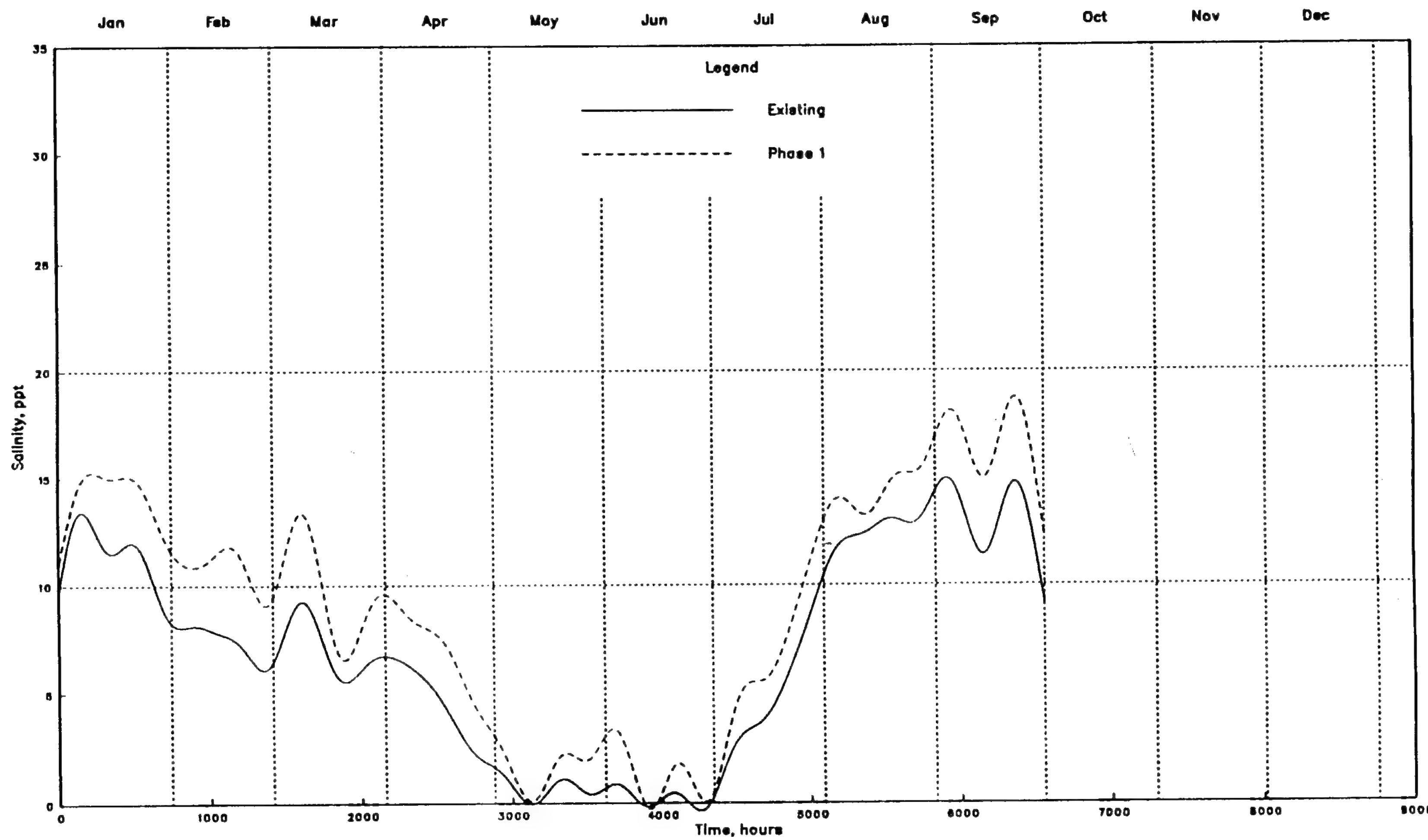
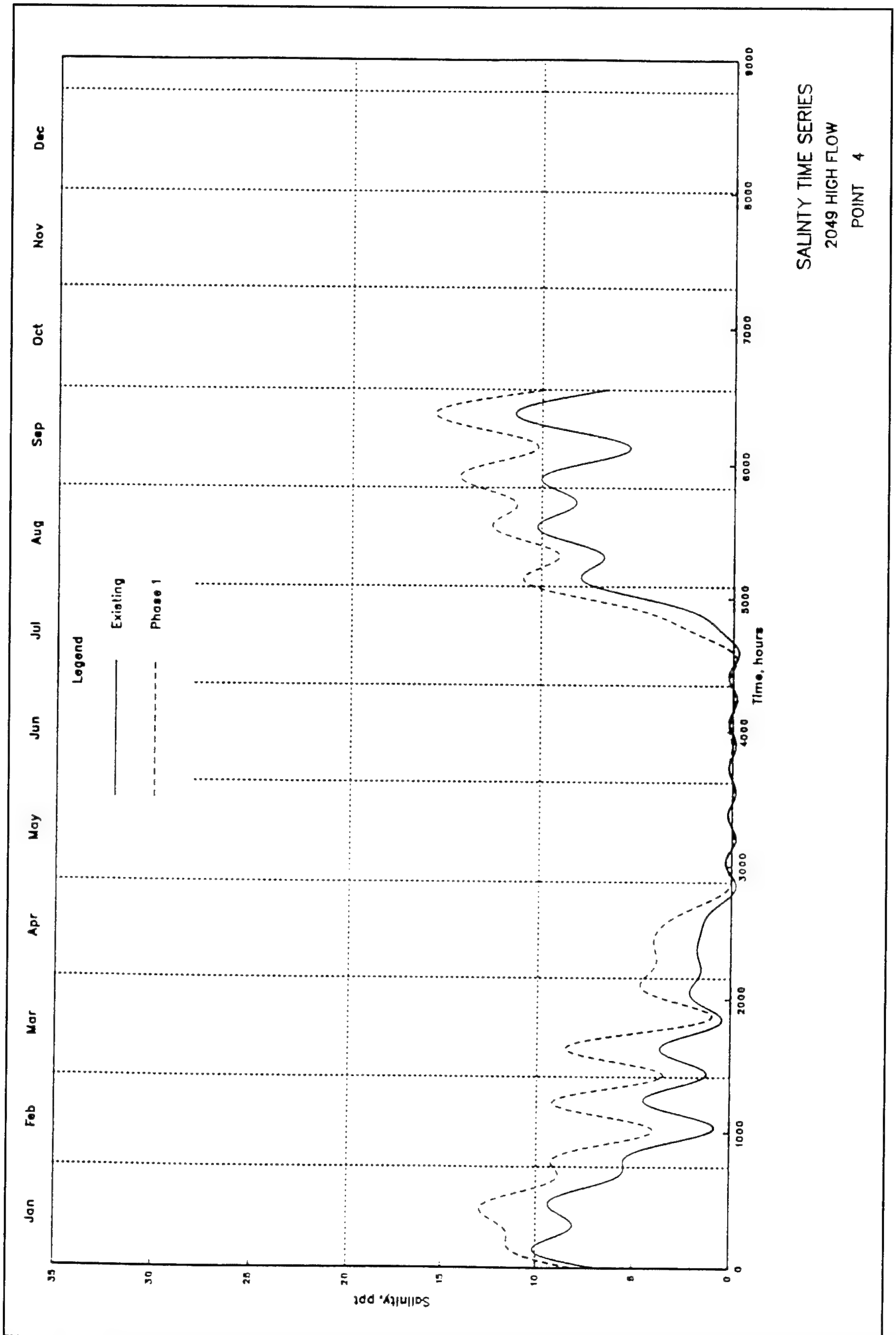


SALINTY TIME SERIES
2049 HIGH FLOW
POINT 3

Plate 147



SALINTY TIME SERIES
2049 HIGH FLOW
POINT 4
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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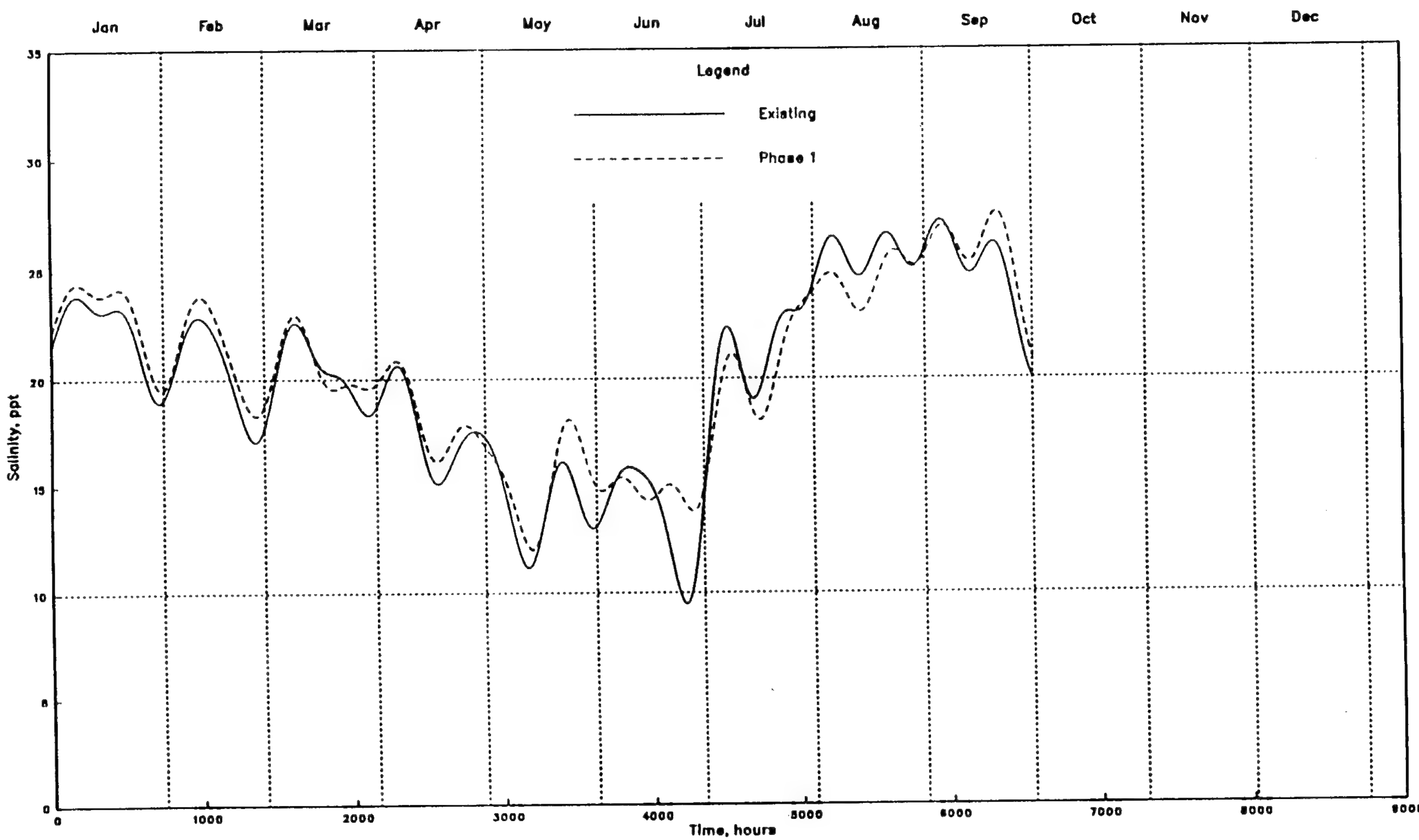
Plate 148



SALINTY TIME SERIES
2049 HIGH FLOW
POINT 5

Plate 149

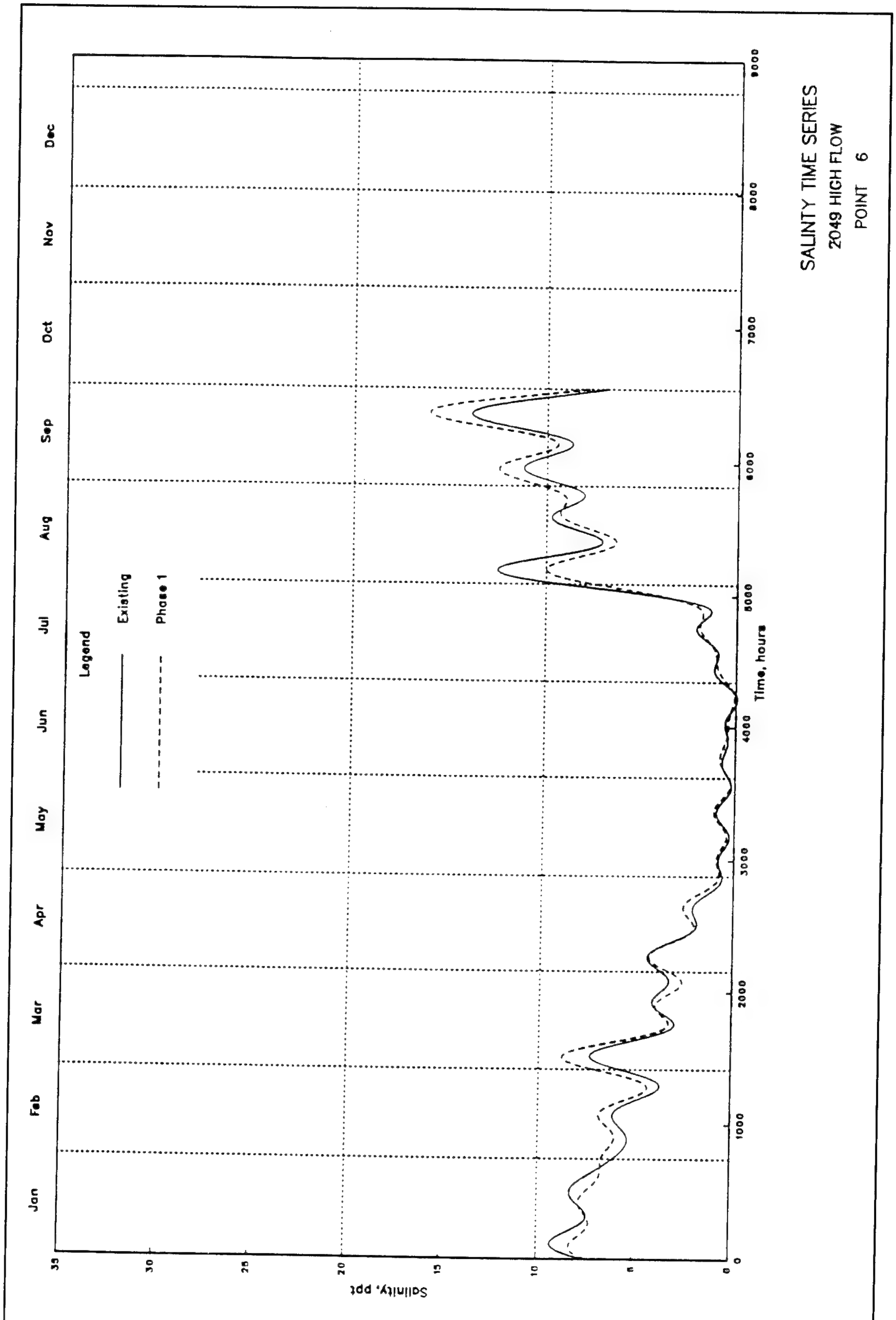

SALINTY TIME SERIES
2049 HIGH FLOW
POINT 6
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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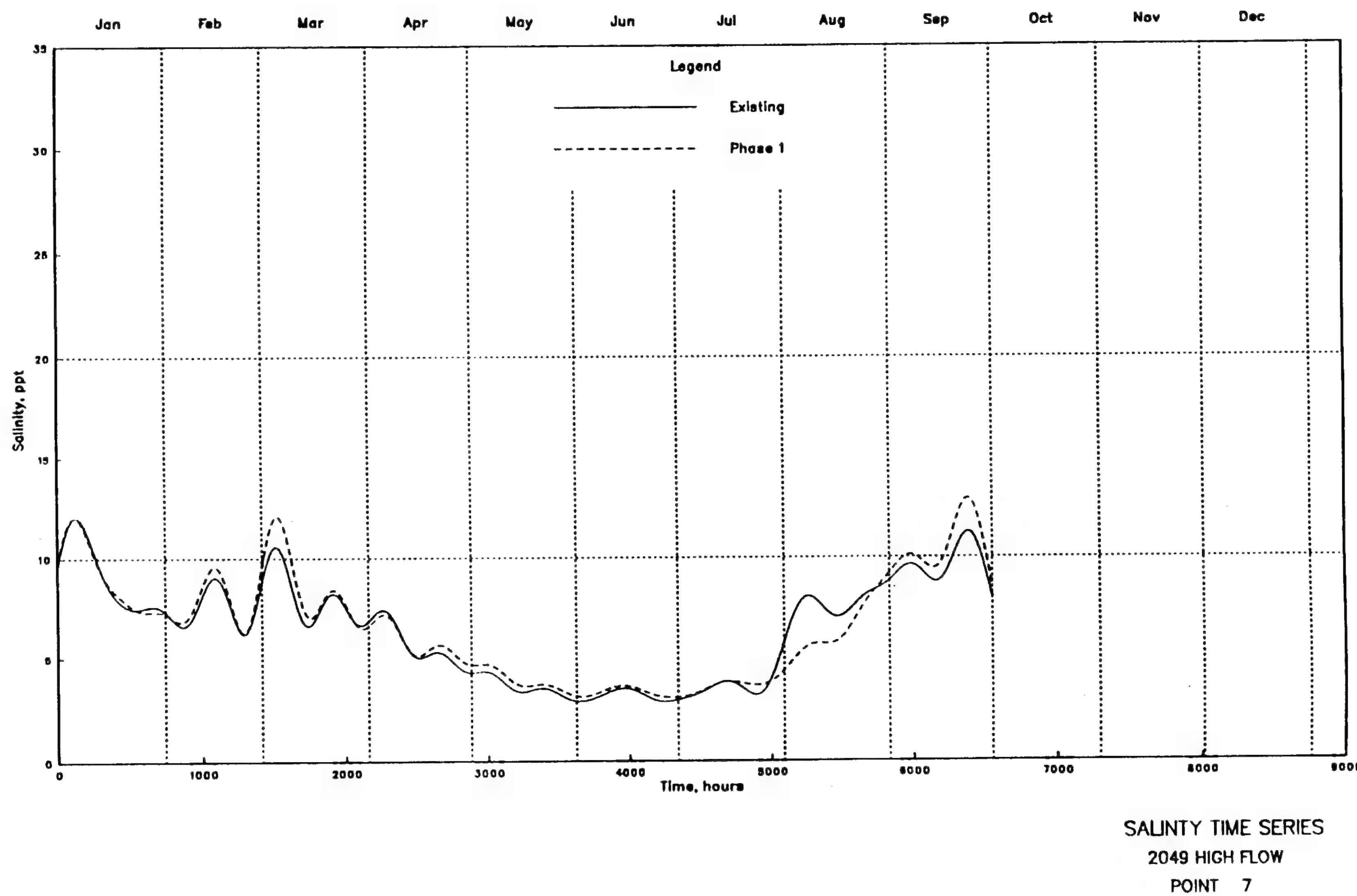
Plate 150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Legend
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Phase 1
Salinity, ppt
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Time, hours
SALINTY TIME SERIES
2049 HIGH FLOW
POINT 7

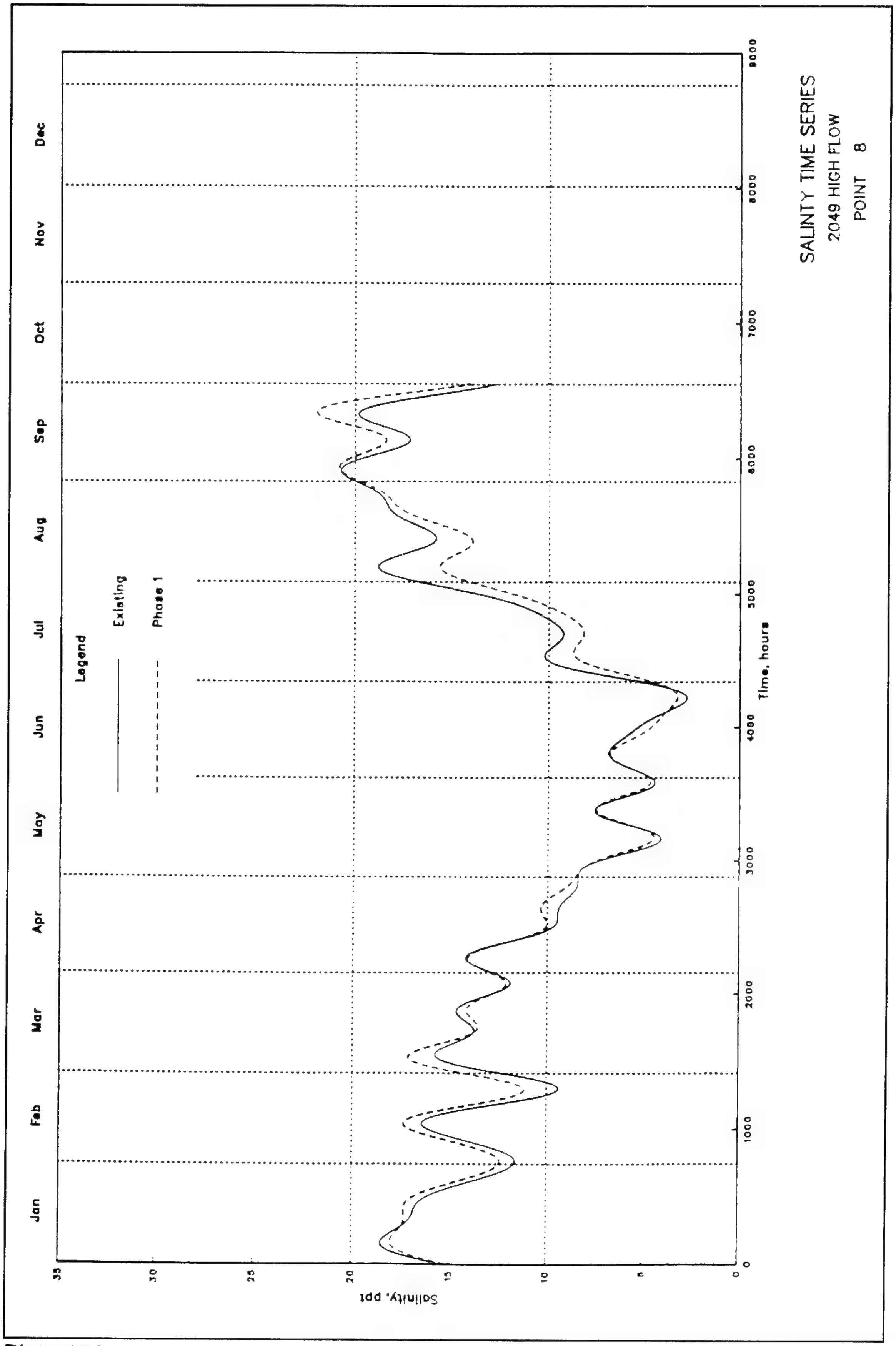
SALINTY TIME SERIES
2049 HIGH FLOW
POINT 8
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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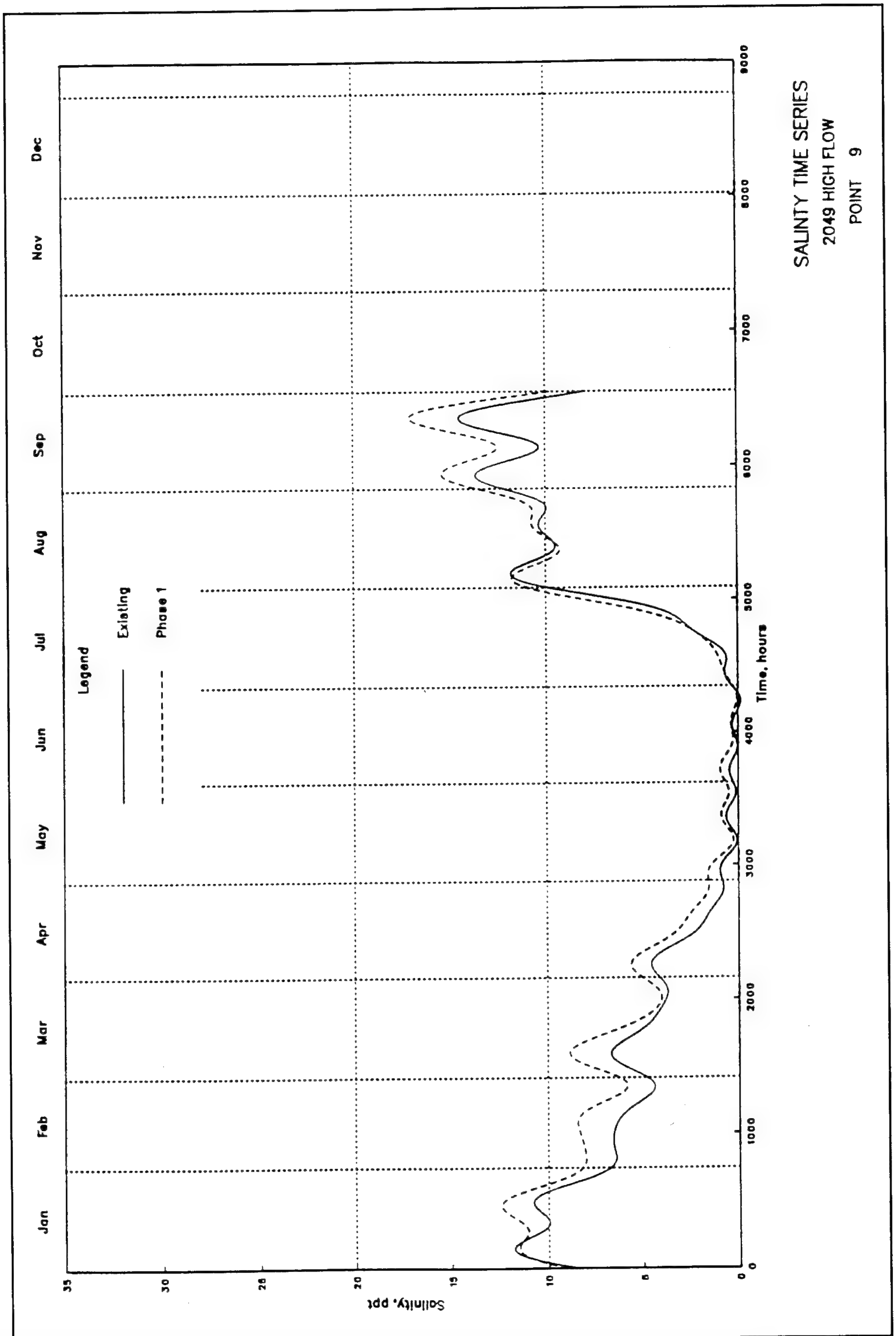
Plate 152


SALINTY TIME SERIES
2049 HIGH FLOW
POINT 9
Legend
Existing
Phase 1
Time, hours
Salinity, ppt
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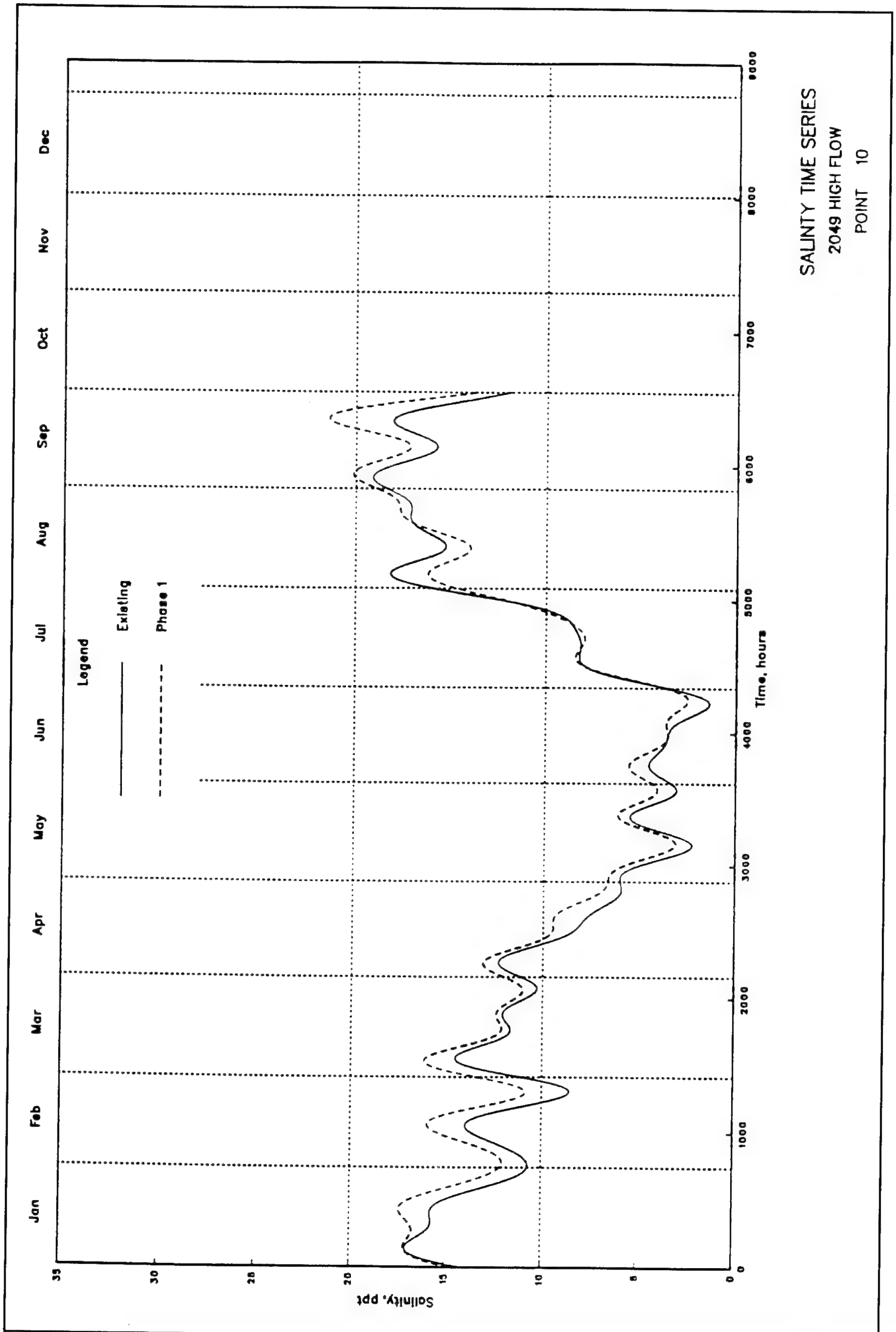
SALINTY TIME SERIES
2049 HIGH FLOW
POINT 10
Legend
Existing
Phase 1
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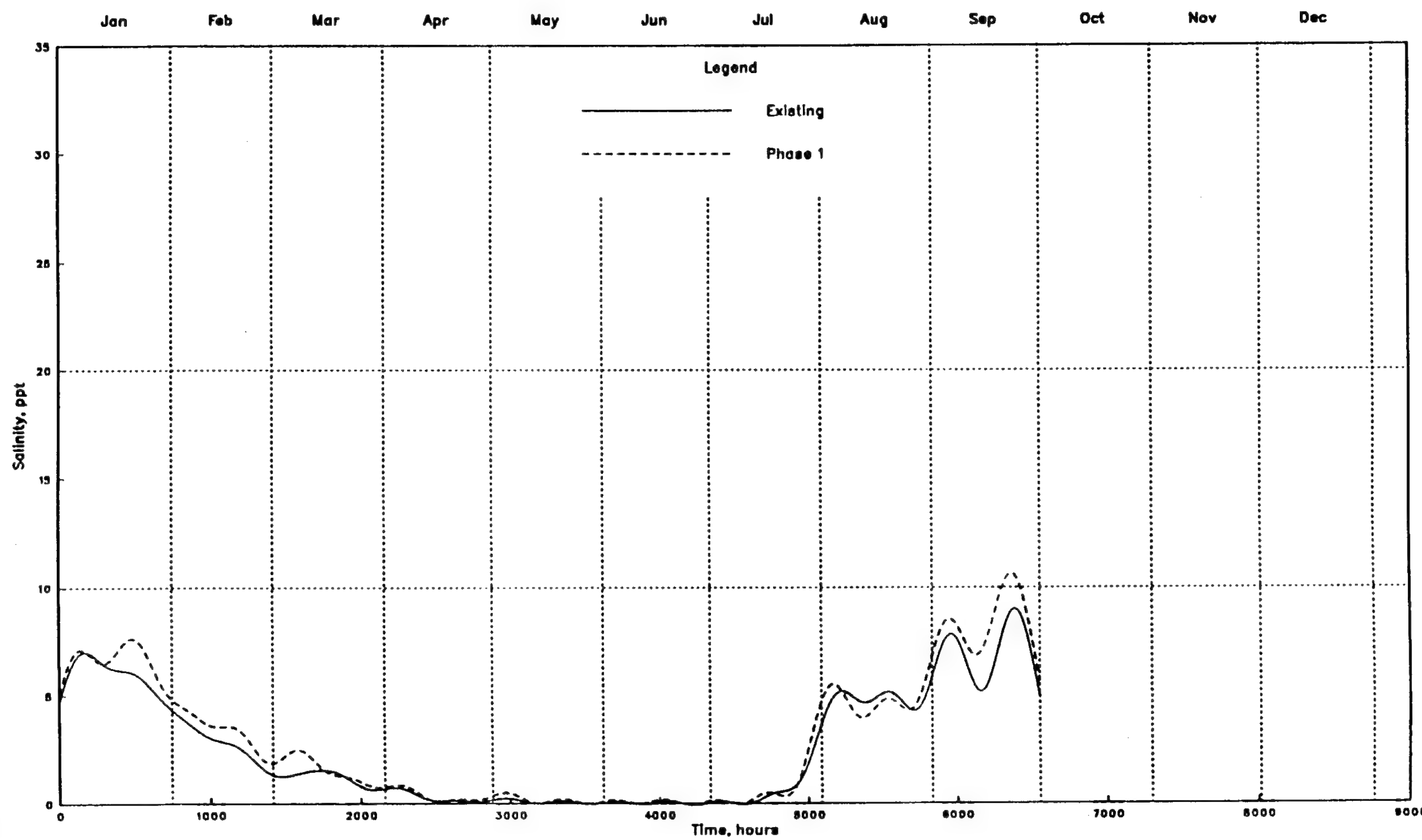
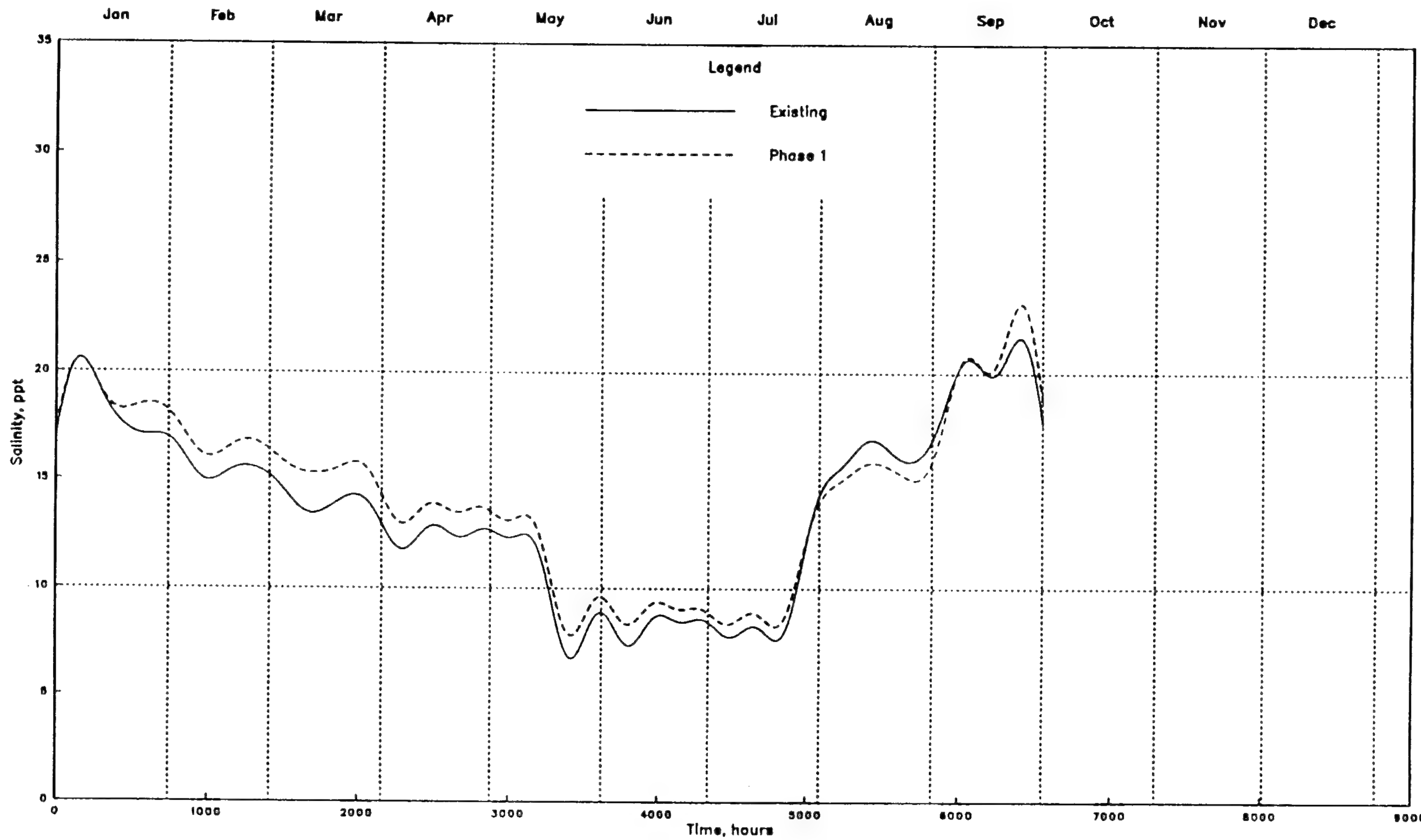
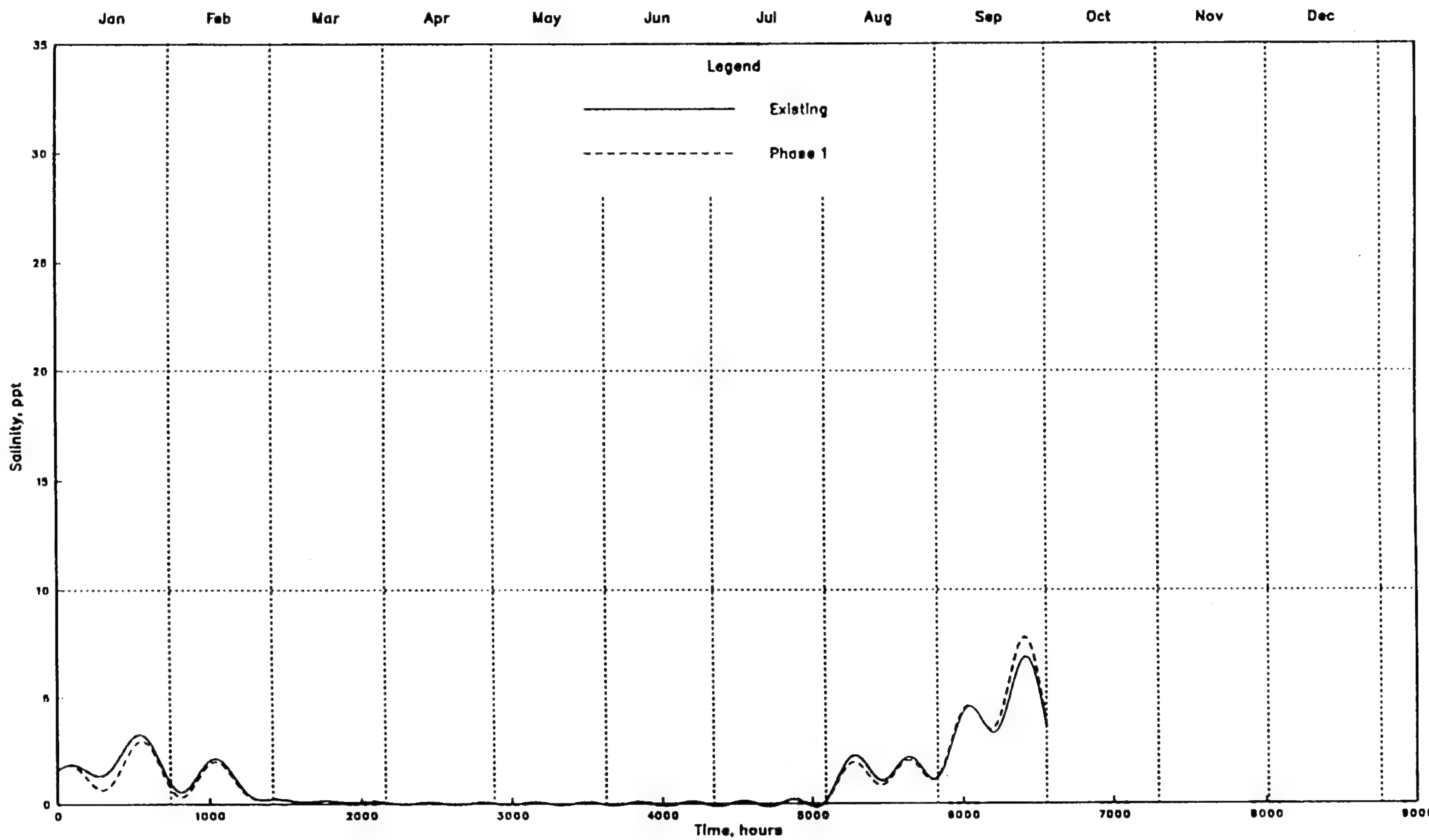
Plate 154



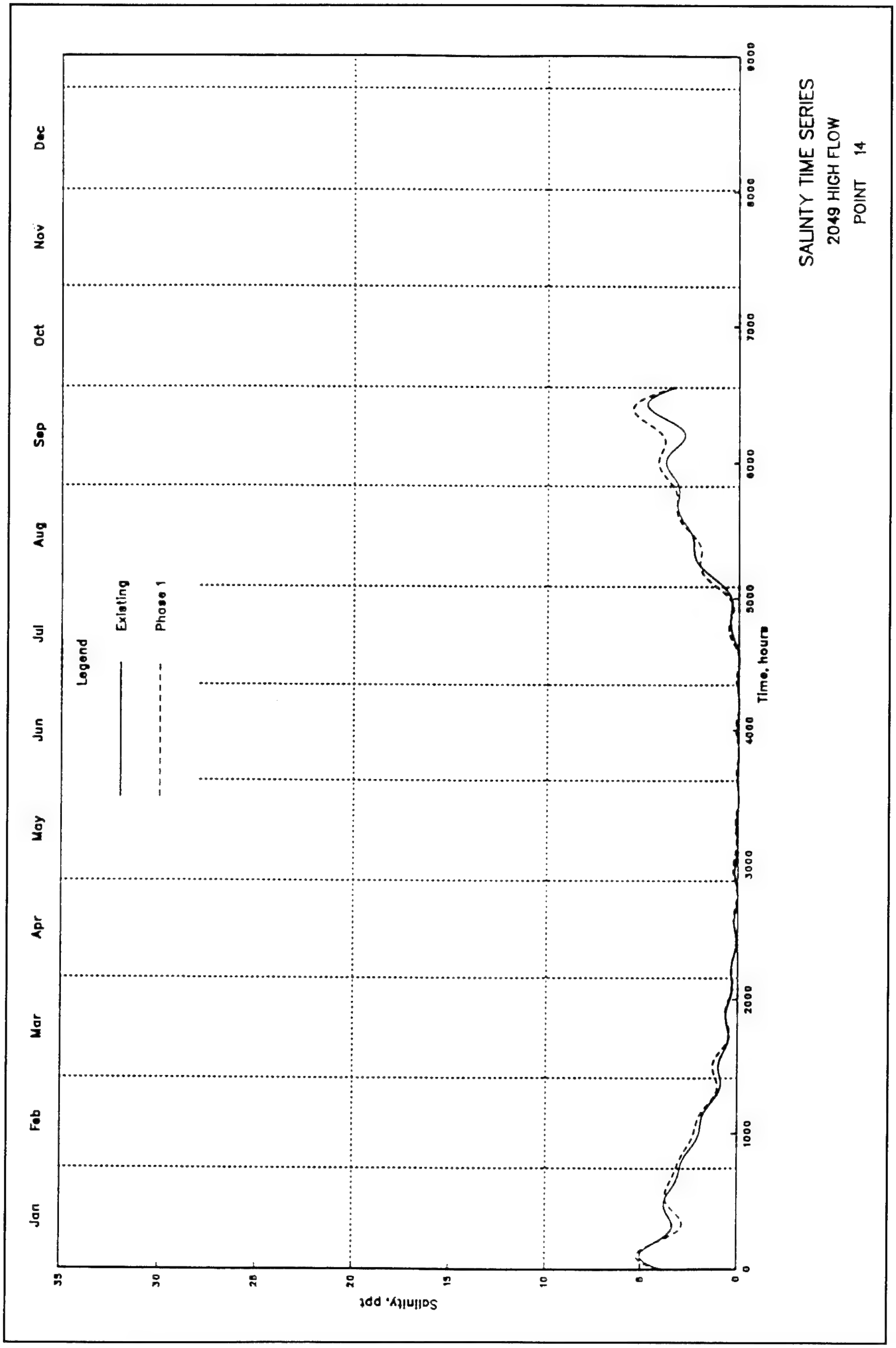
SALINTY TIME SERIES
2049 HIGH FLOW
POINT 11



SALINTY TIME SERIES
2049 HIGH FLOW
POINT 12



SALINTY TIME SERIES
2049 HIGH FLOW
POINT 13



SALINTY TIME SERIES
2049 HIGH FLOW
POINT 14
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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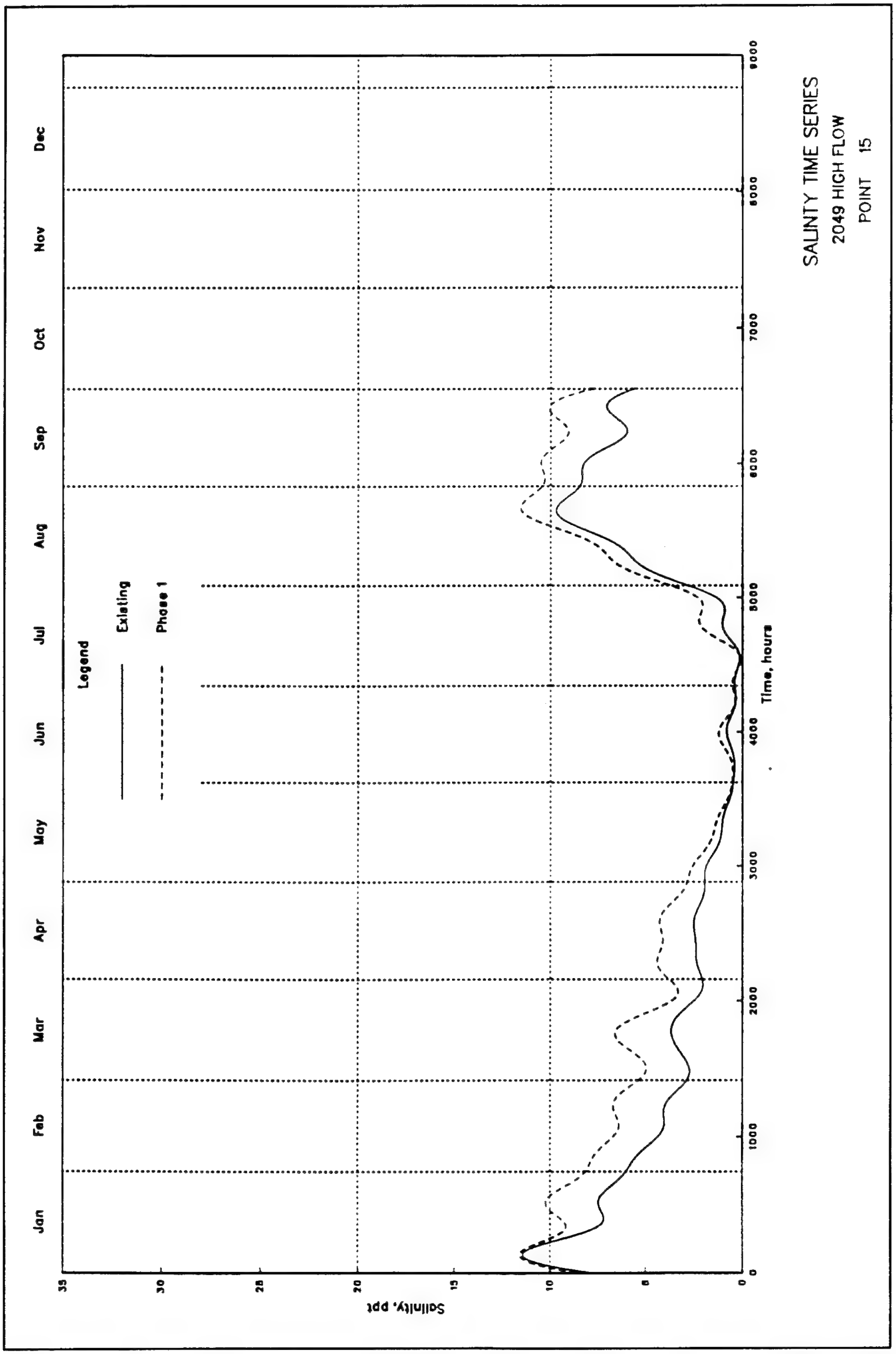
Plate 158


SALINTY TIME SERIES
2049 HIGH FLOW
POINT 15
Legend
Existing
Phase 1
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Salinity, ppt
Time, hours
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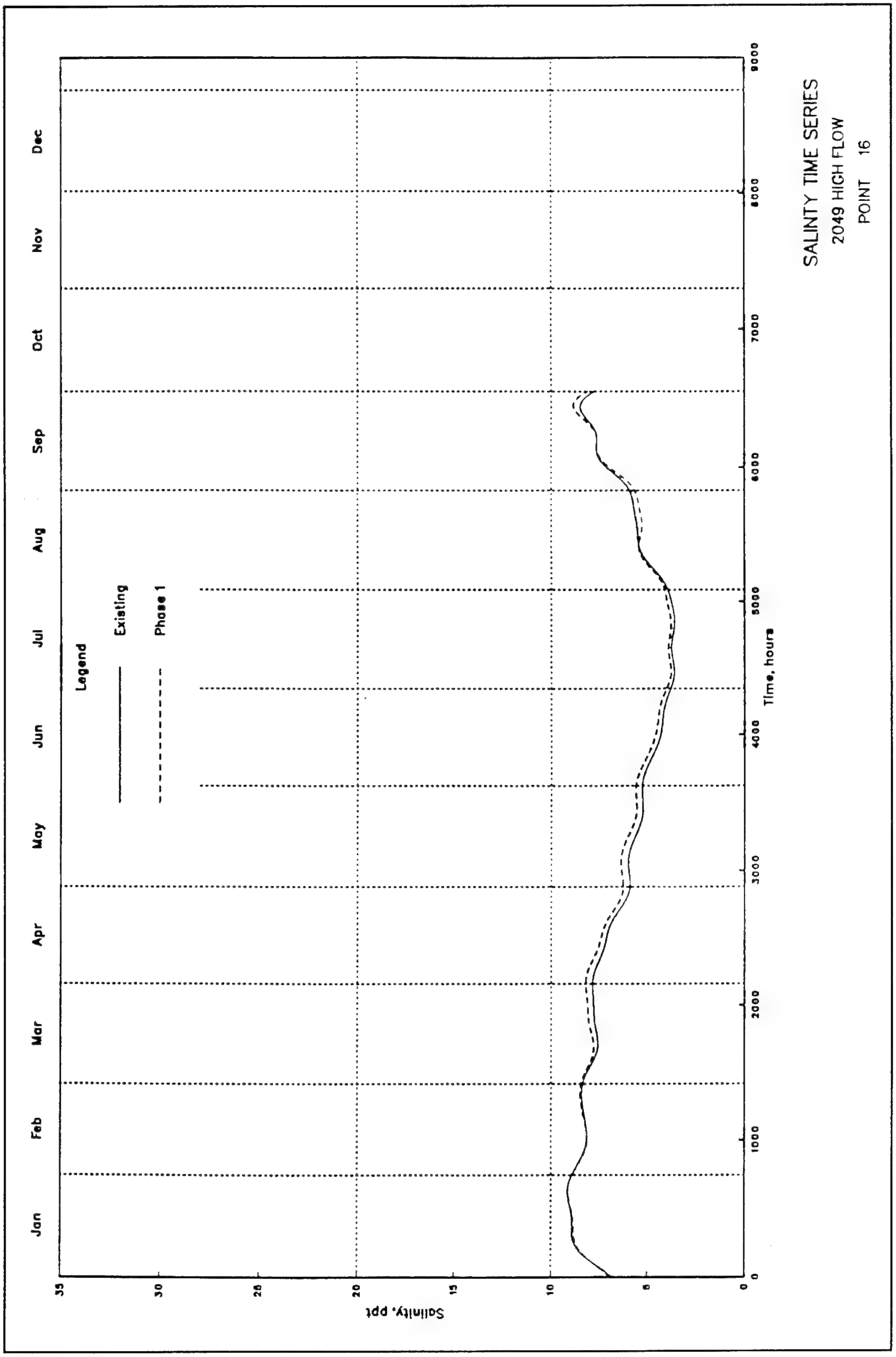
SALINTY TIME SERIES
2049 HIGH FLOW
POINT 16
Legend
Existing
Phase 1
Salinity, ppt
Time, hours
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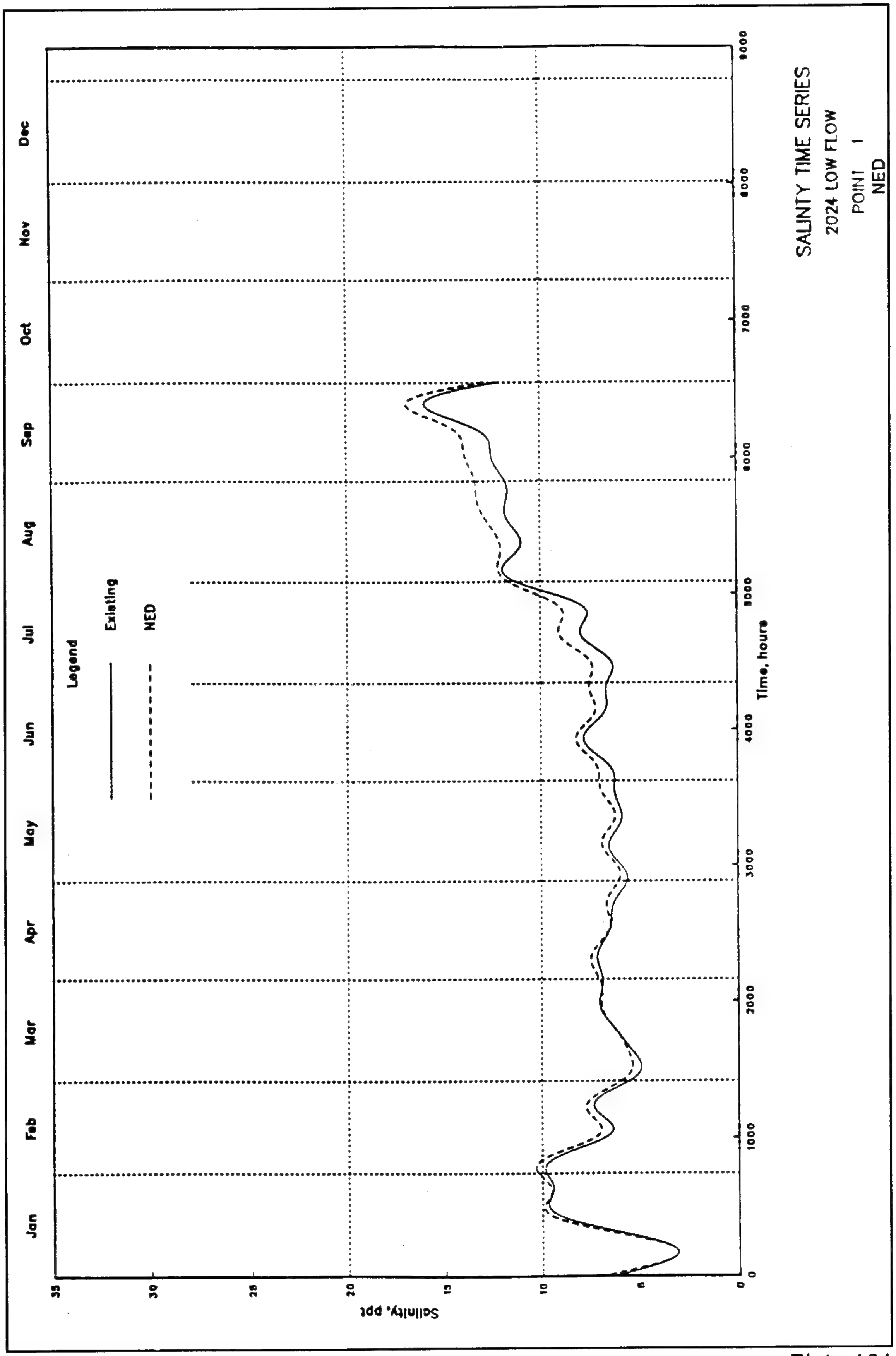
SALINTY TIME SERIES
2024 LOW FLOW
POINT 1
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Legend
Existing
NED
Salinity, ppt
Time, hours
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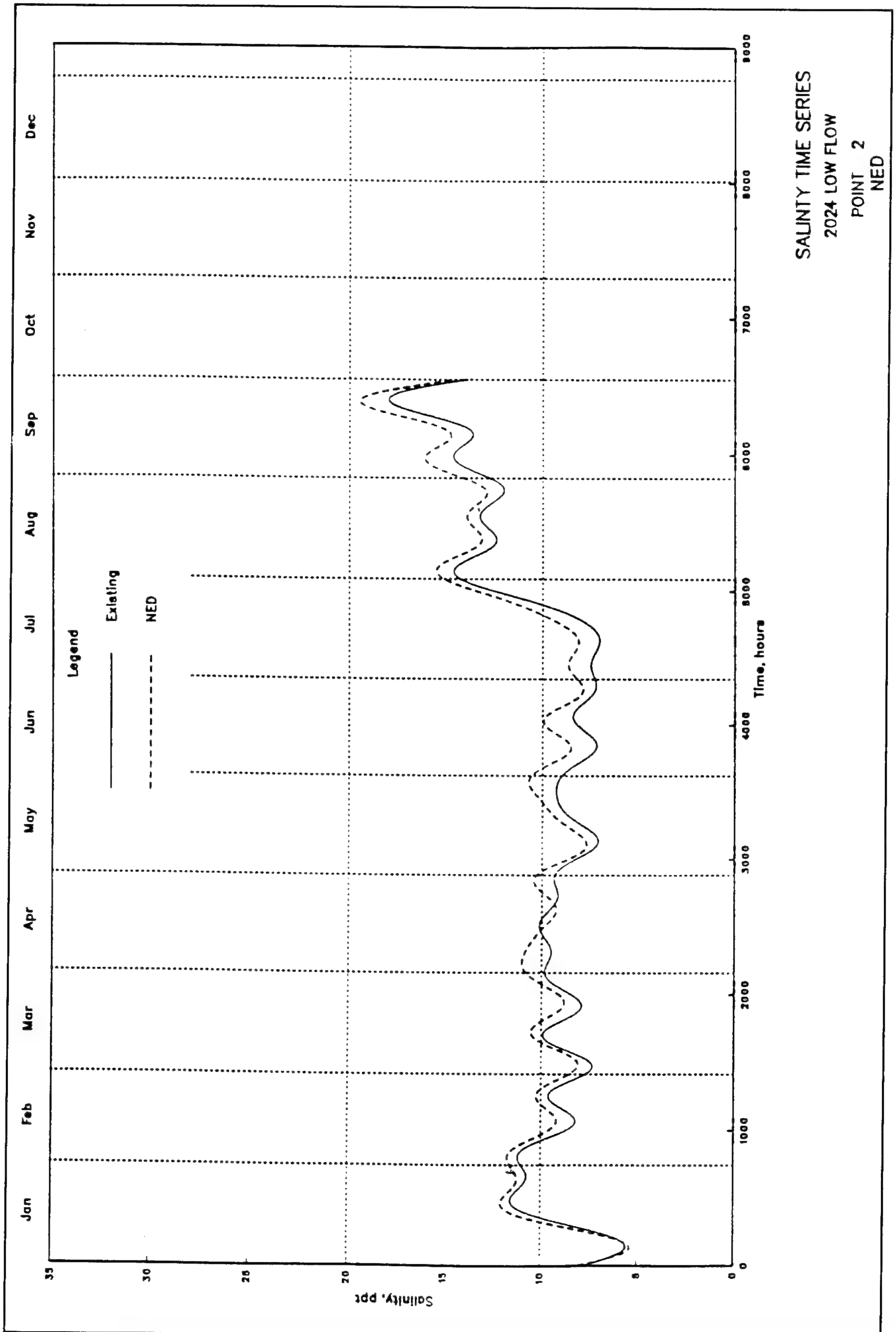

SALINTY TIME SERIES
2024 LOW FLOW
POINT 2
NED
Legend
Existing
NED
Time, hours
Salinity, ppt
Jan
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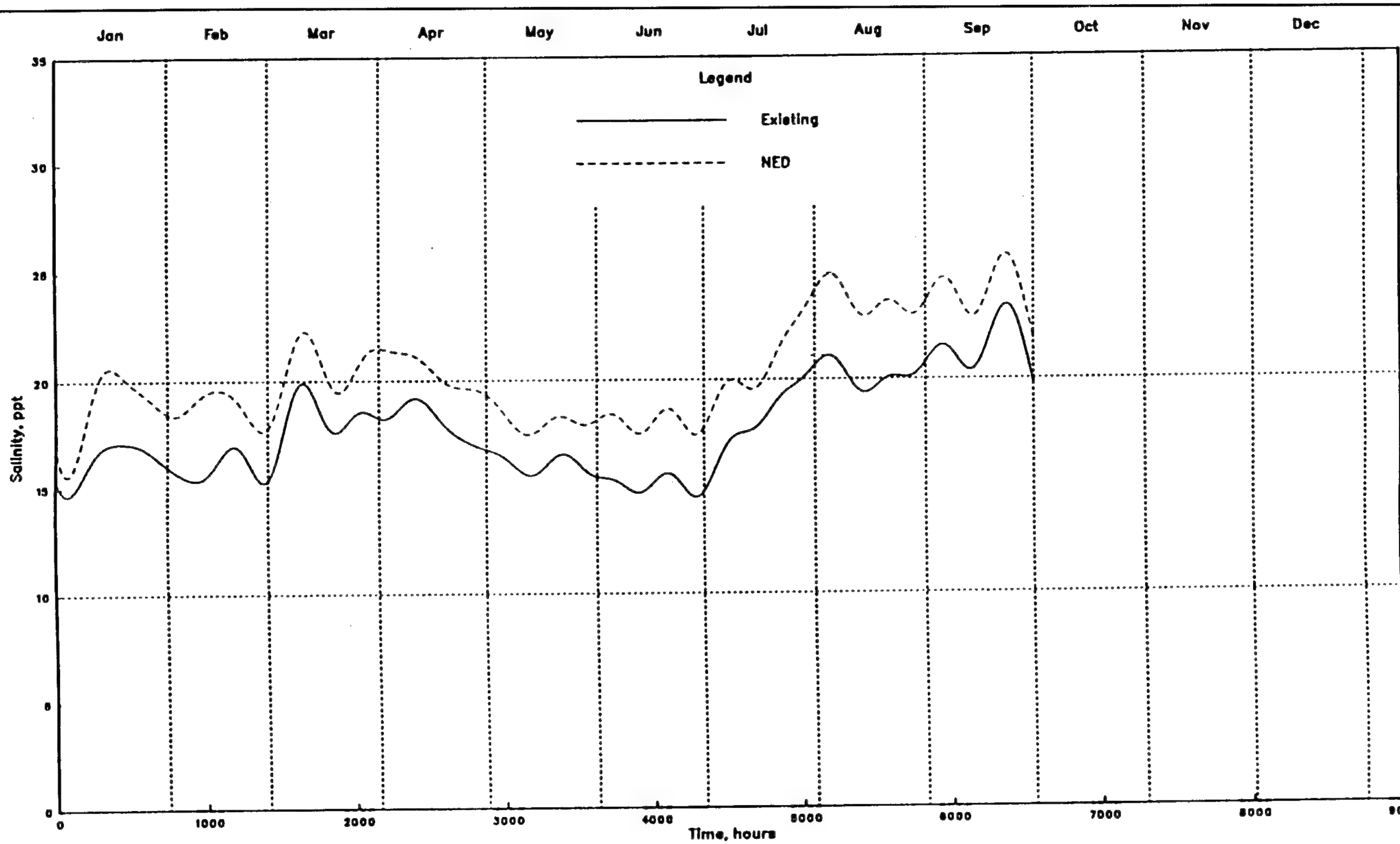
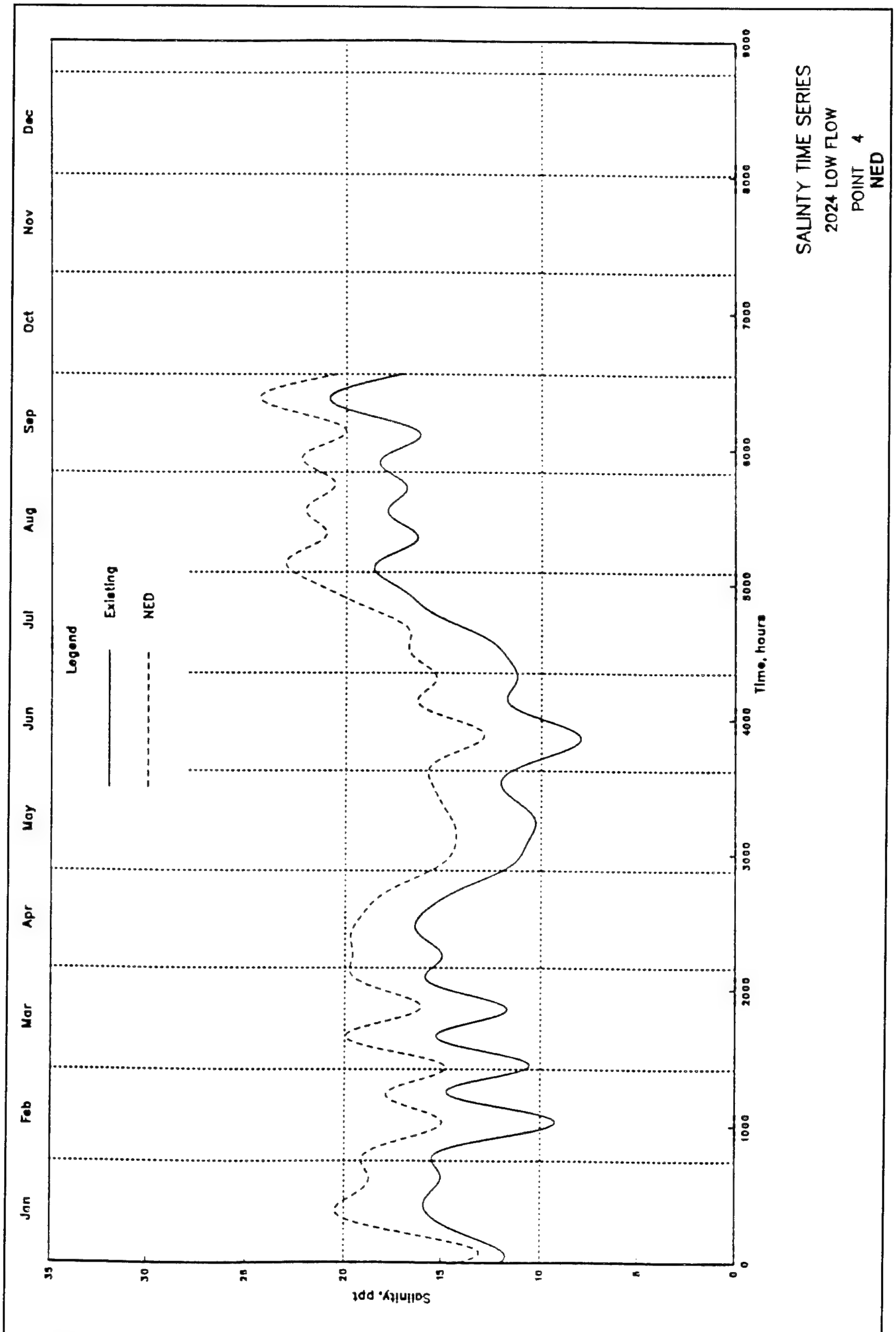
Plate 162



SALINTY TIME SERIES
2024 LOW FLOW
POINT 3
NED



SALINTY TIME SERIES
2024 LOW FLOW
POINT 4
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Legend
Existing
NED
Time, hours
Salinity, ppt
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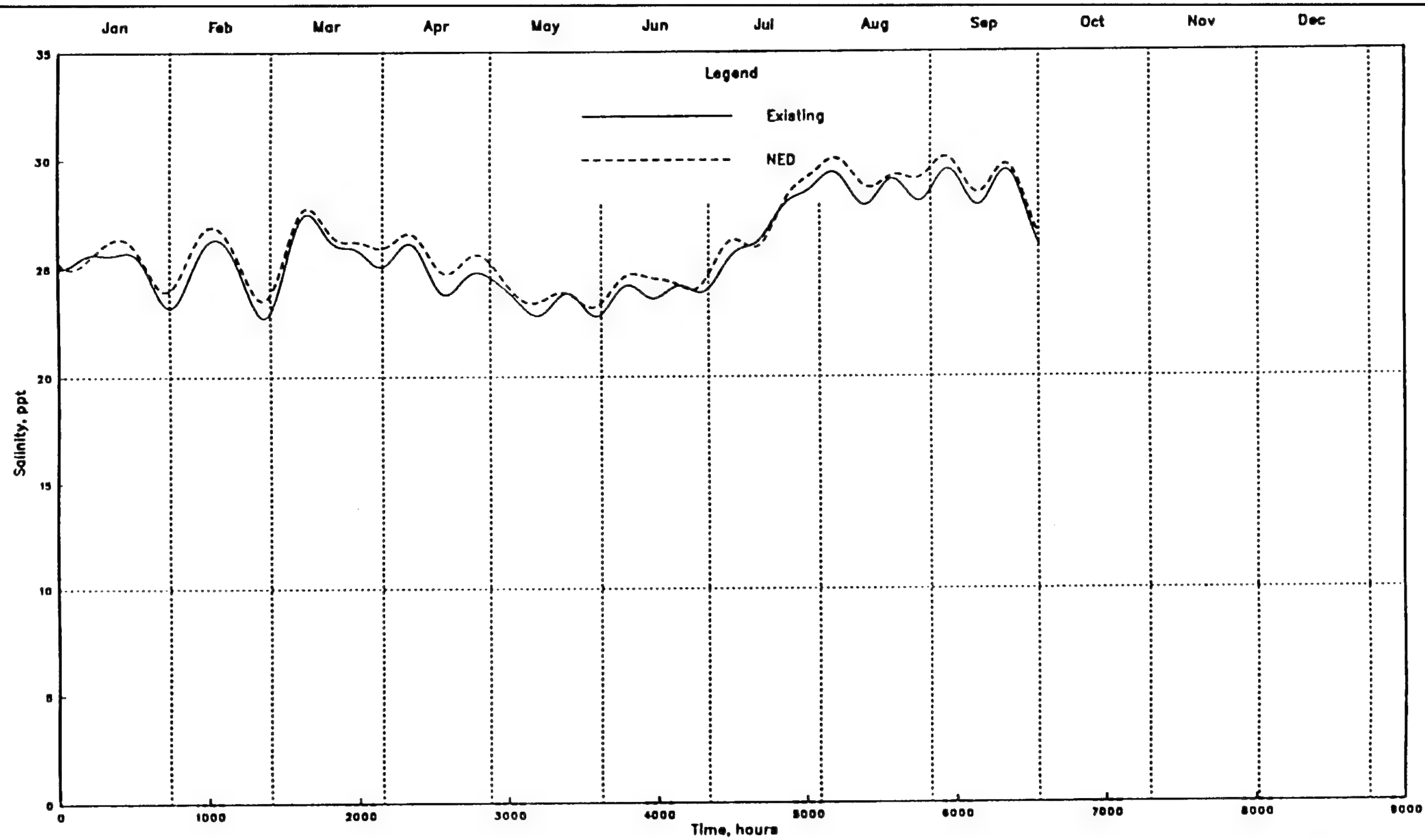
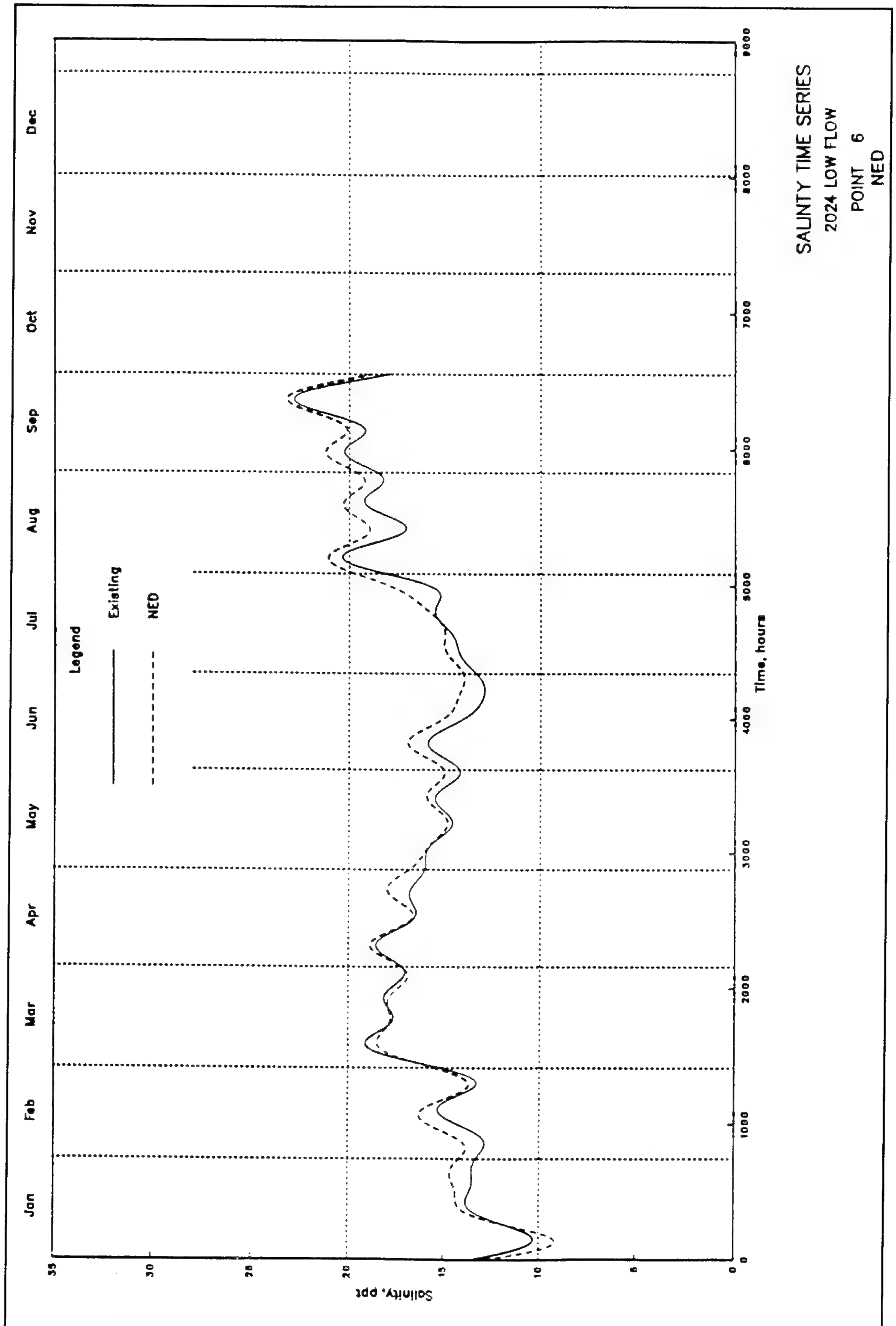
Plate 164



SALINTY TIME SERIES
2024 LOW FLOW
POINT 5
NED



SALINTY TIME SERIES
2024 LOW FLOW
POINT 6
NED
Legend
Existing
NED
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Sep
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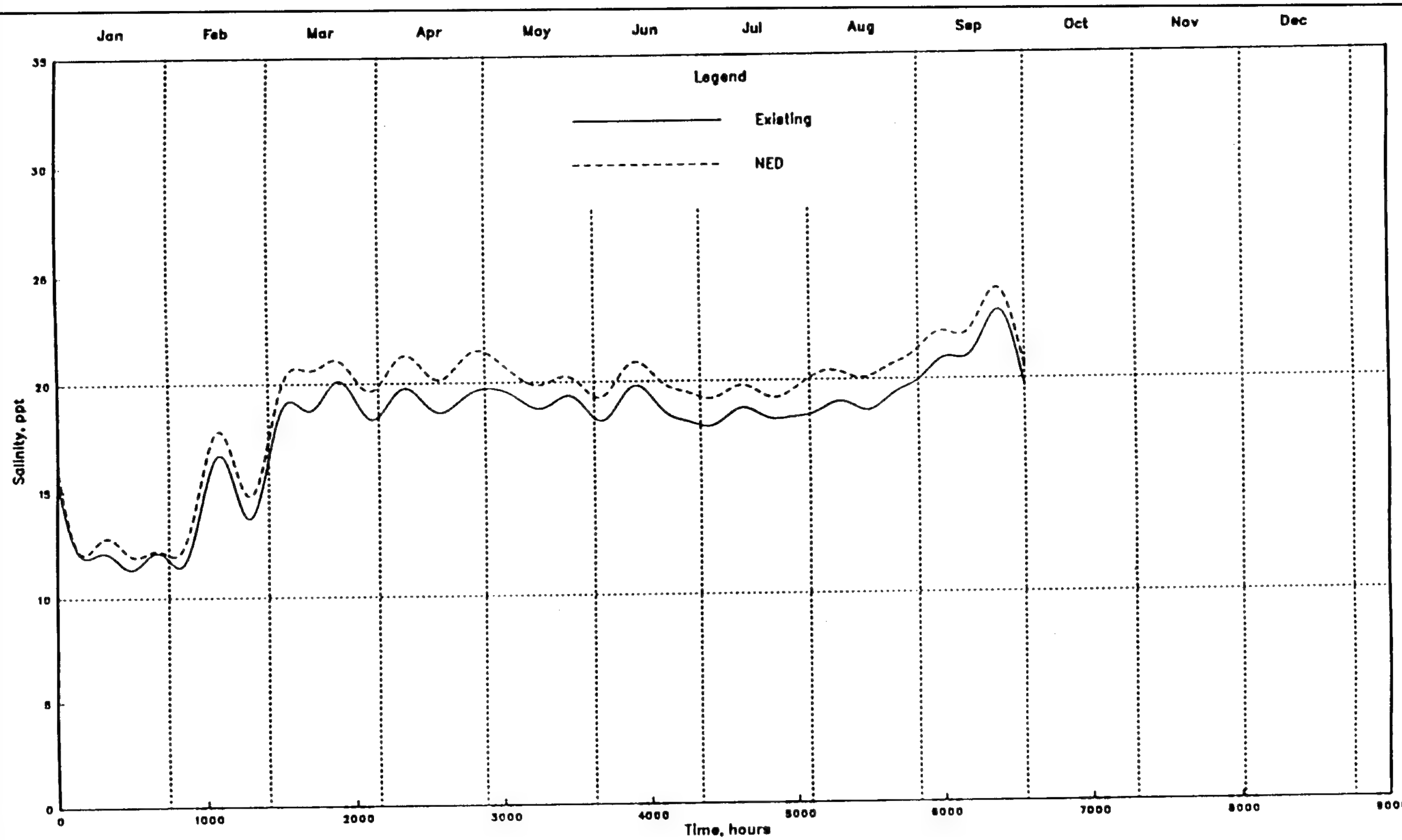
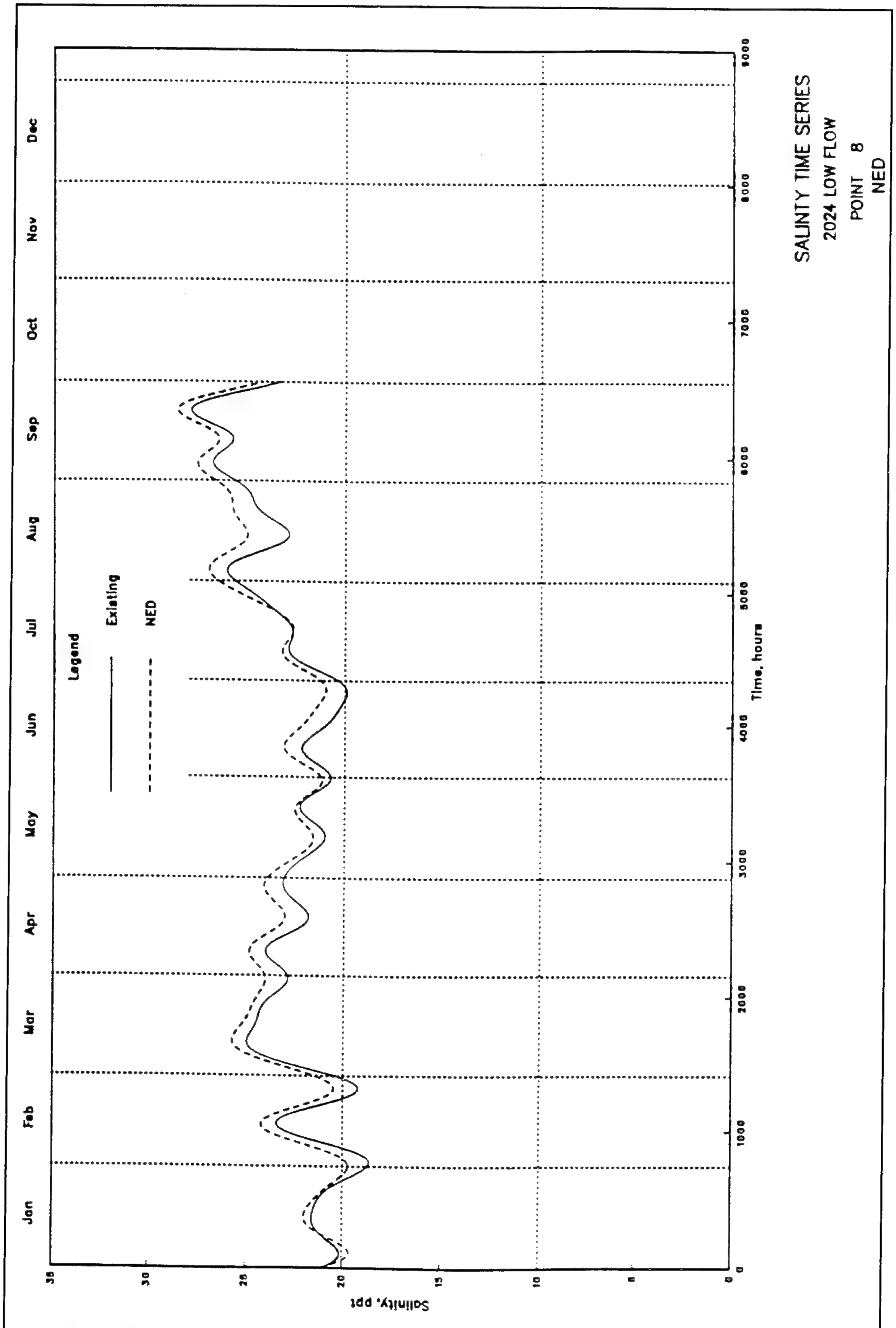
Nov
Dec
Time, hours
Salinity, ppt

Plate 166



SALINTY TIME SERIES
2024 LOW FLOW
POINT 7
NED



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Salinity, ppt
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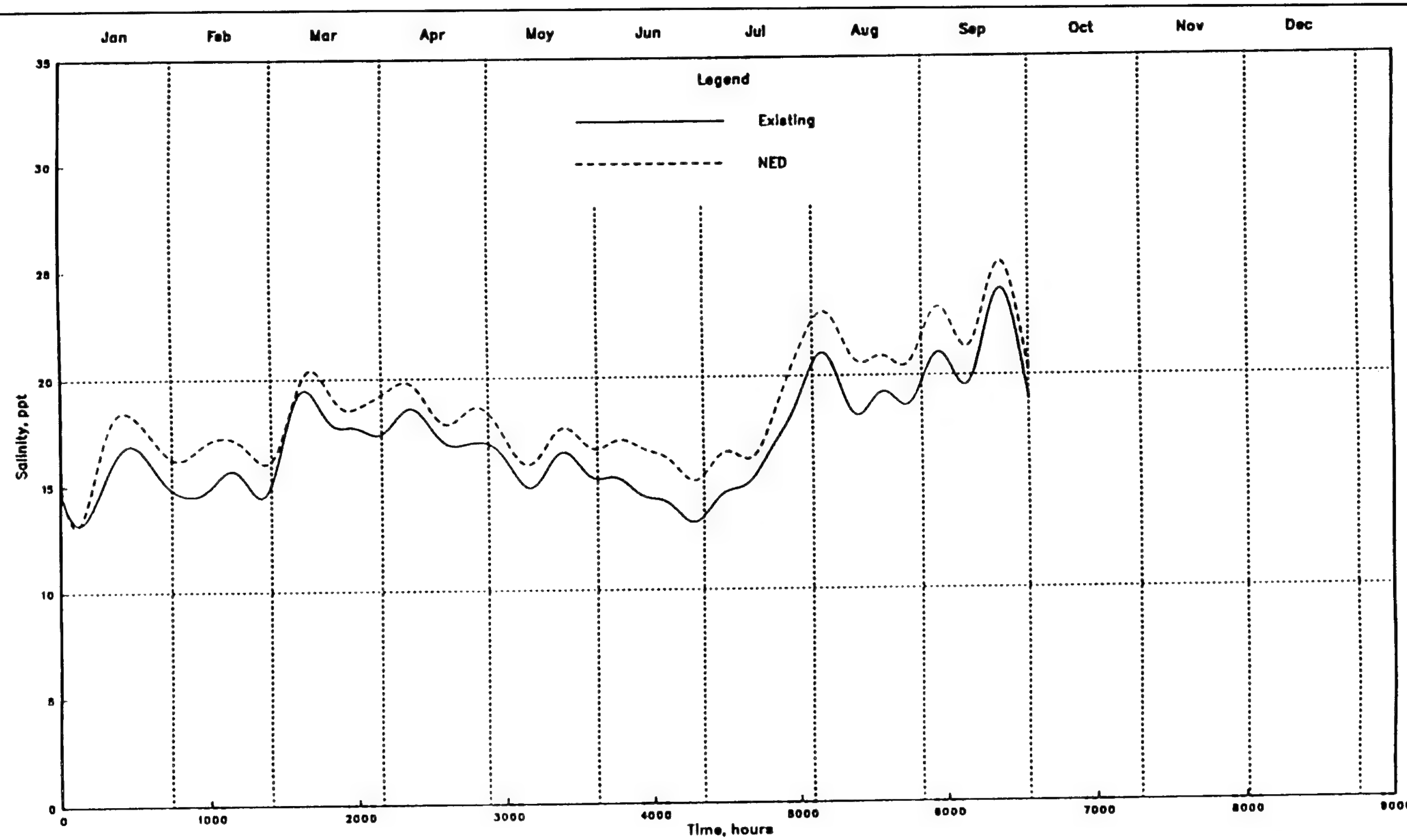
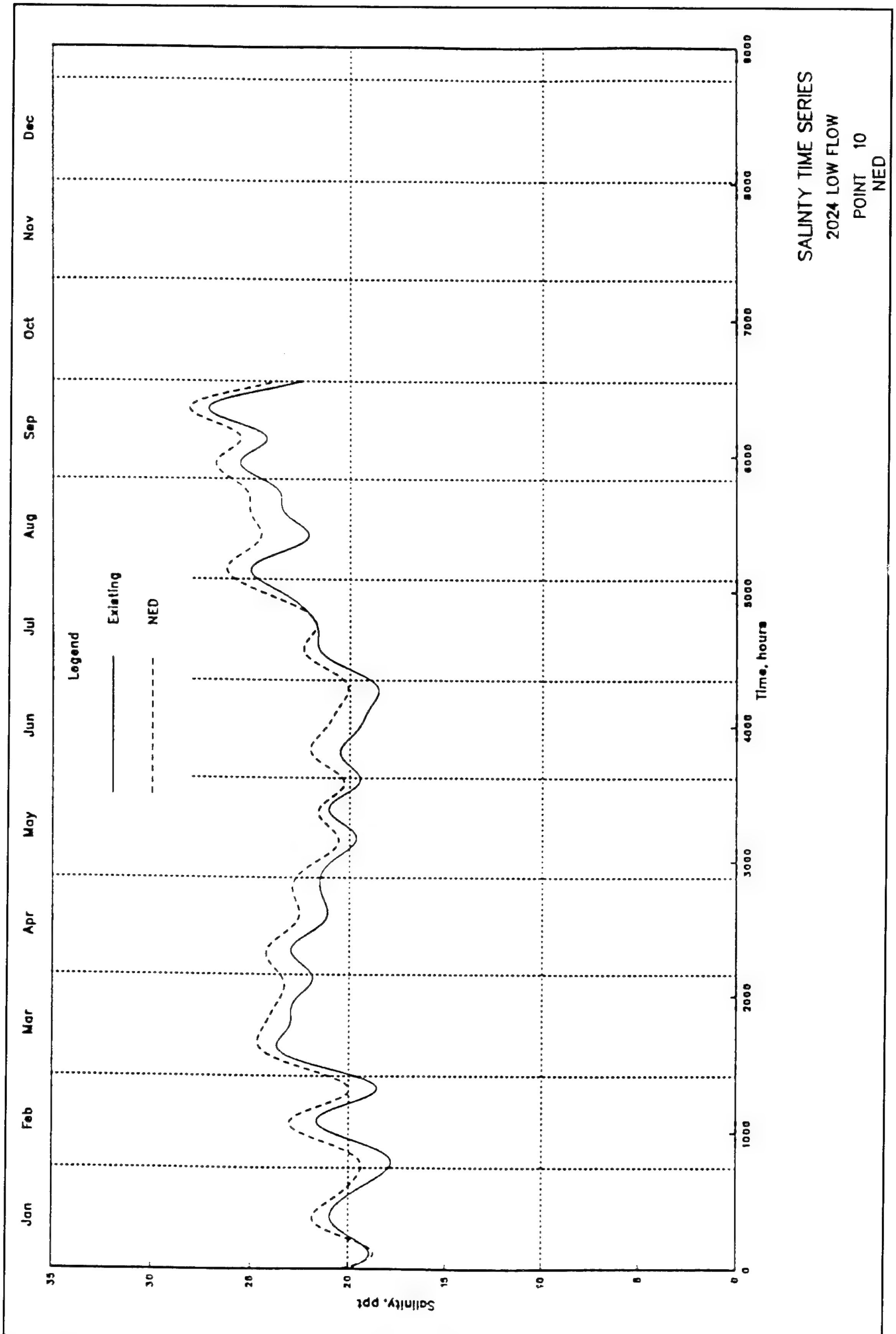
SALINTY TIME SERIES
2024 LOW FLOW
POINT 8
NED

Plate 168



SALINTY TIME SERIES
2024 LOW FLOW
POINT 9
NED



SALINTY TIME SERIES
2024 LOW FLOW
POINT 10
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Legend
Existing
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Salinity, ppt
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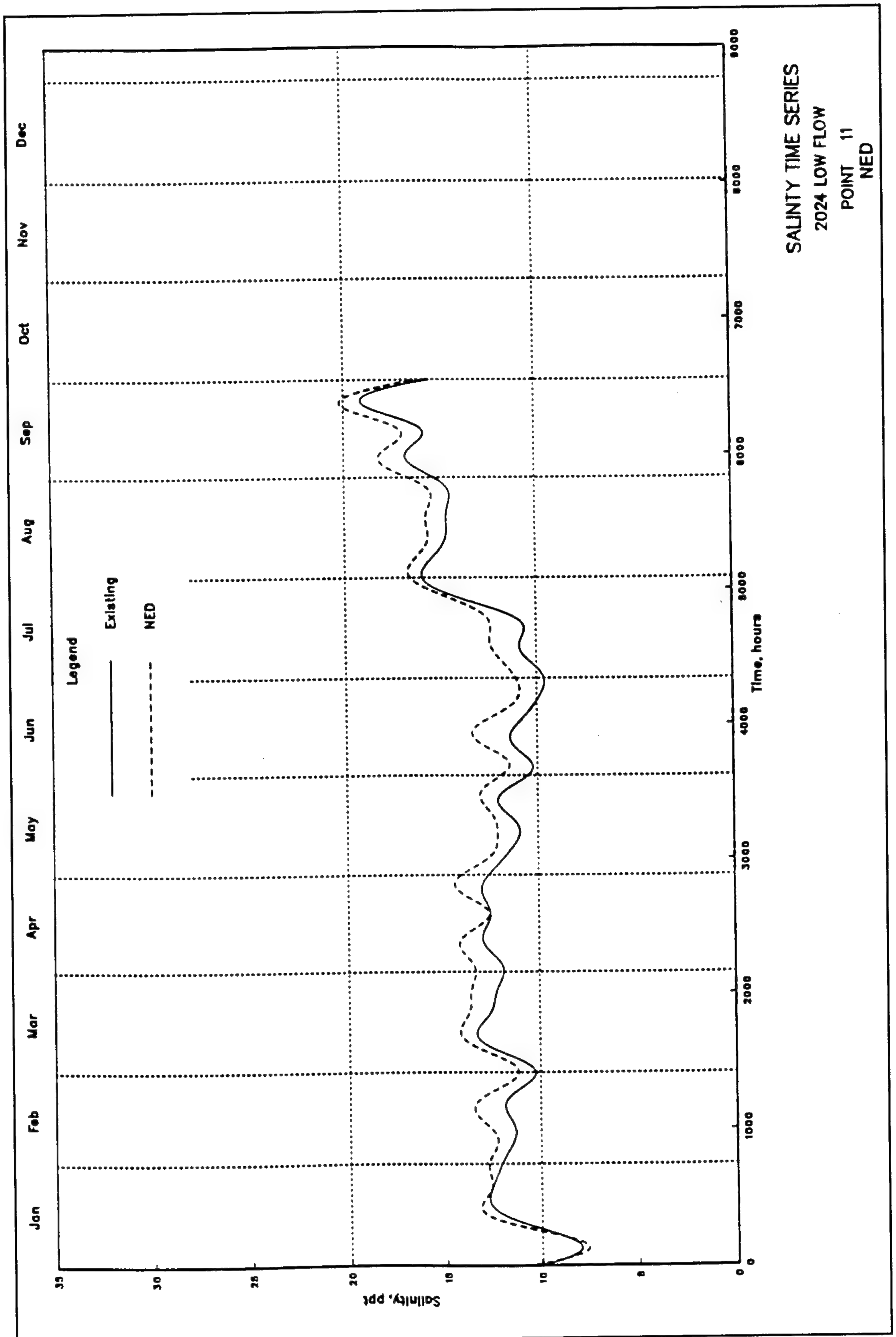
SALINTY TIME SERIES
2024 LOW FLOW
POINT 11
NED
Legend
Existing
NED
Time, hours
Salinity, ppt
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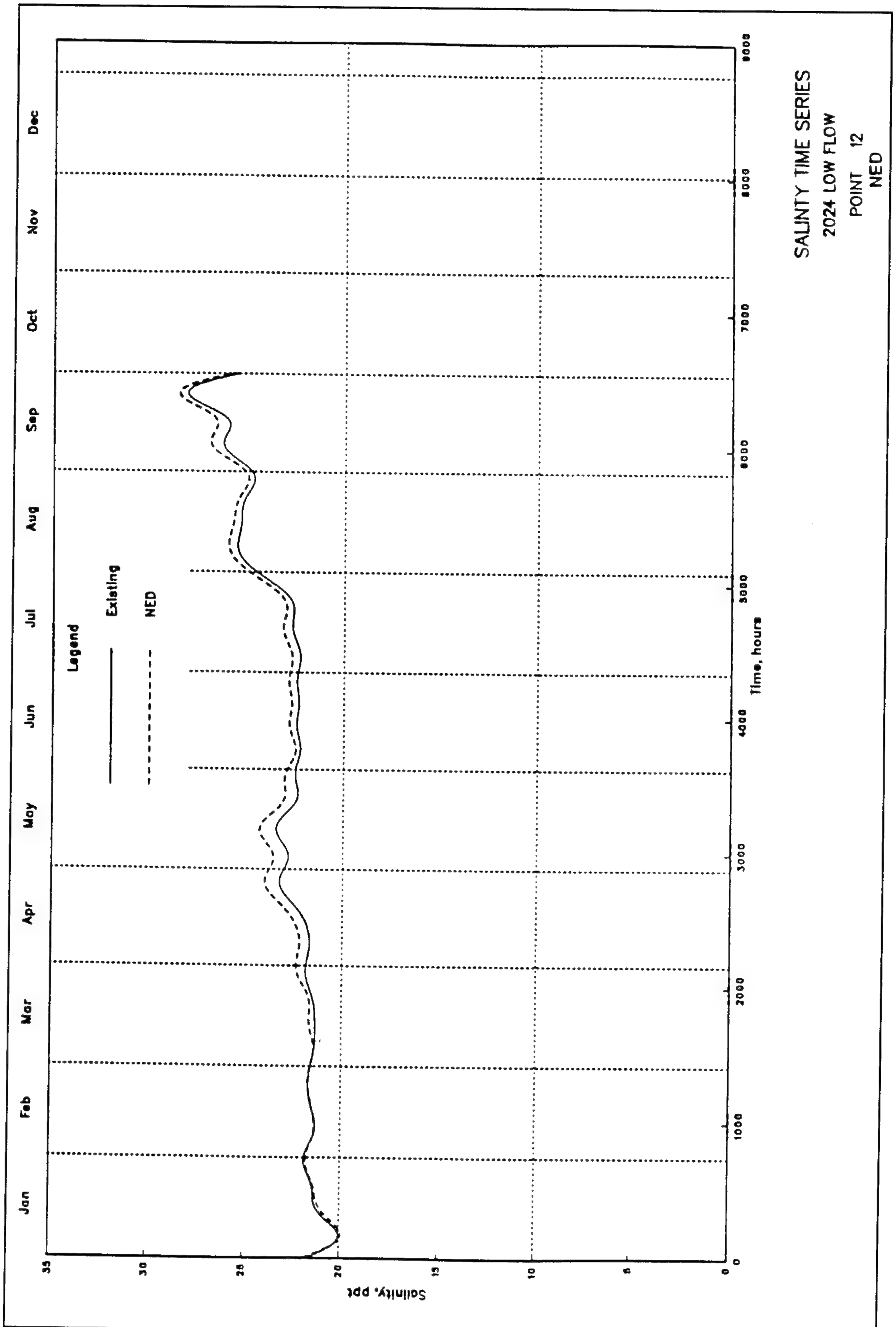
SALINTY TIME SERIES
2024 LOW FLOW
POINT 12
NED
Legend
Existing
NED
Salinity, ppt
Time, hours
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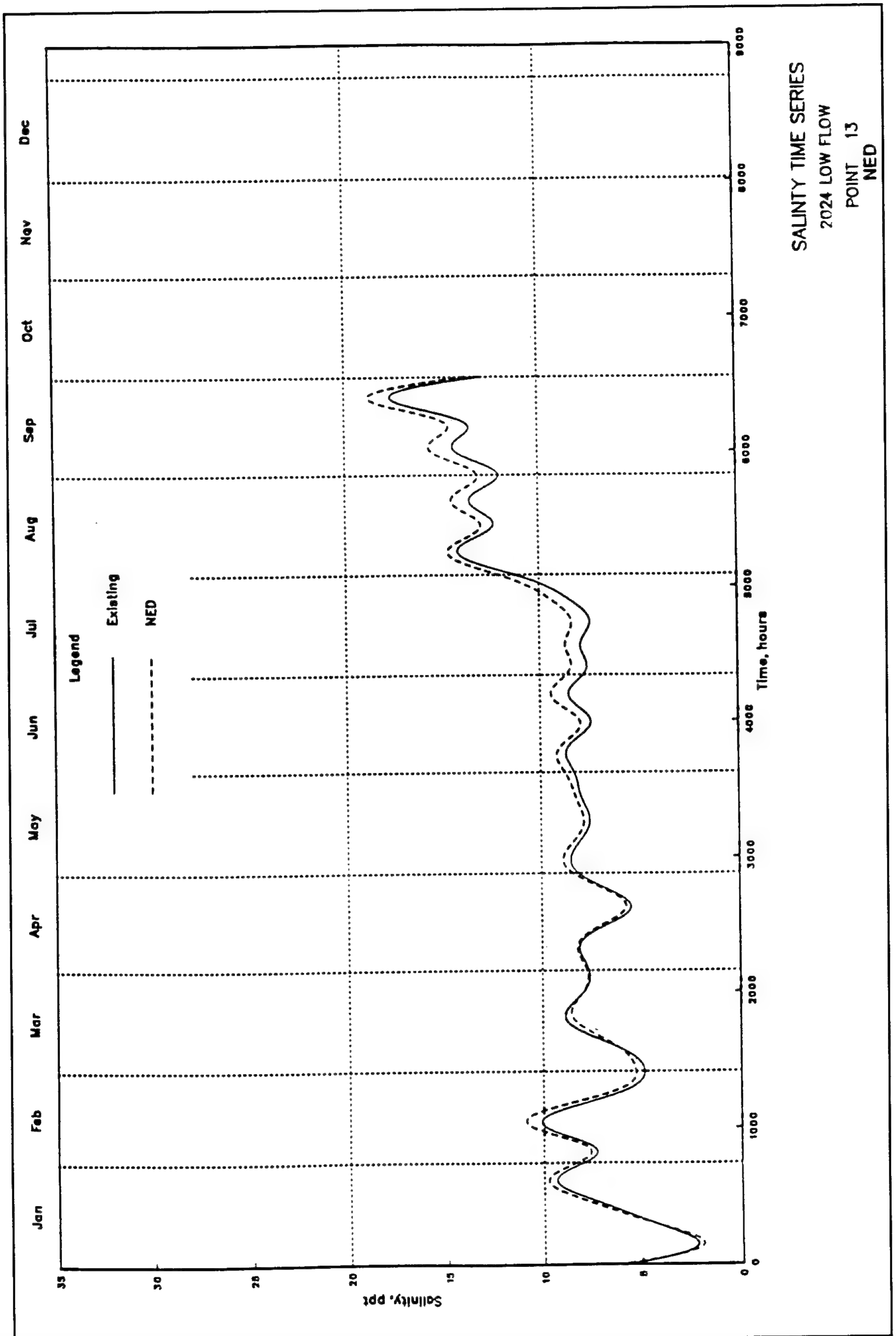
Plate 172


SALINTY TIME SERIES
2024 LOW FLOW
POINT 13
NED
Legend
Existing
NED
Salinity, ppt
Time, hours
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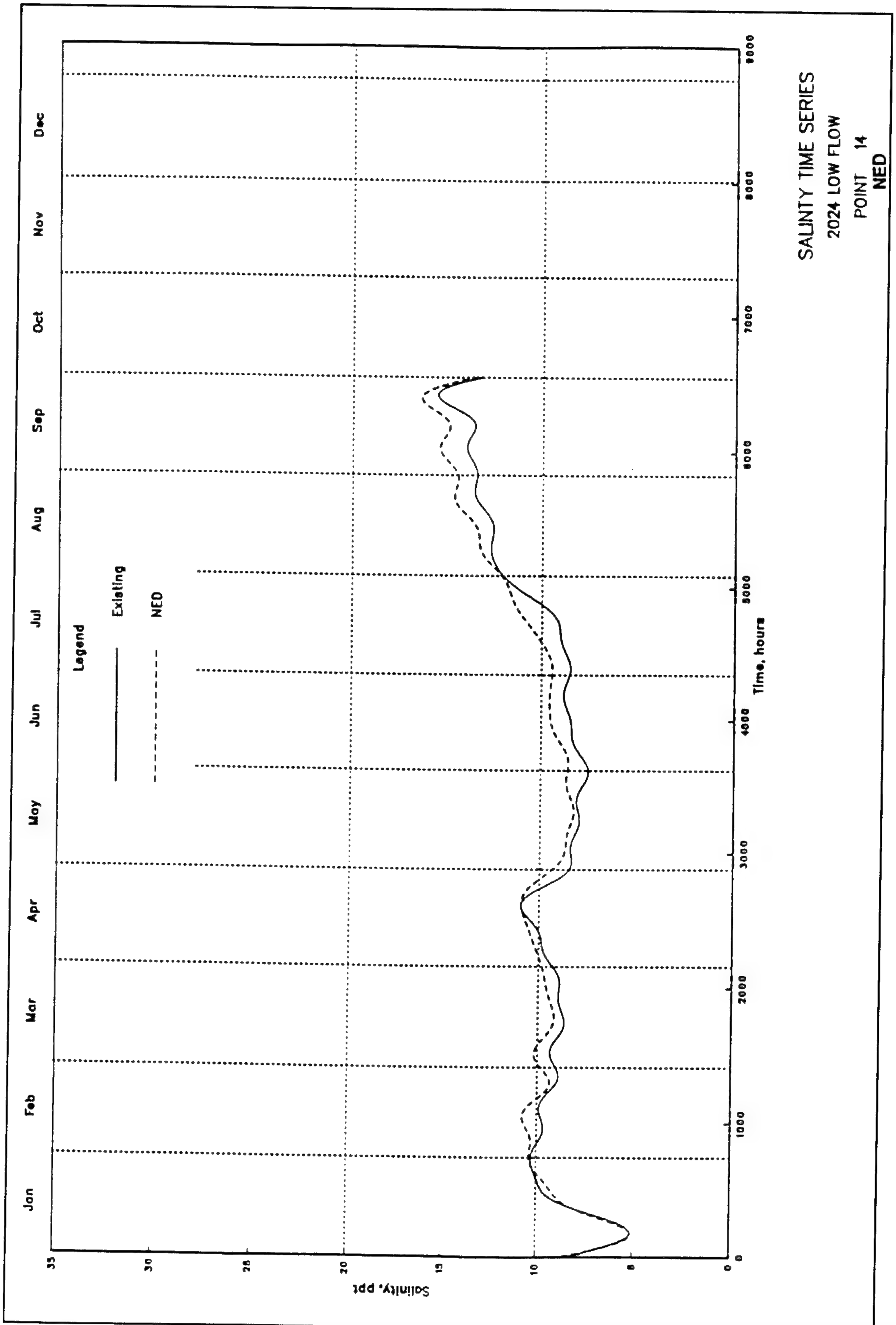

SALINTY TIME SERIES
2024 LOW FLOW
POINT 14
NED
Legend
Existing
NED
Time, hours
Salinity, ppt
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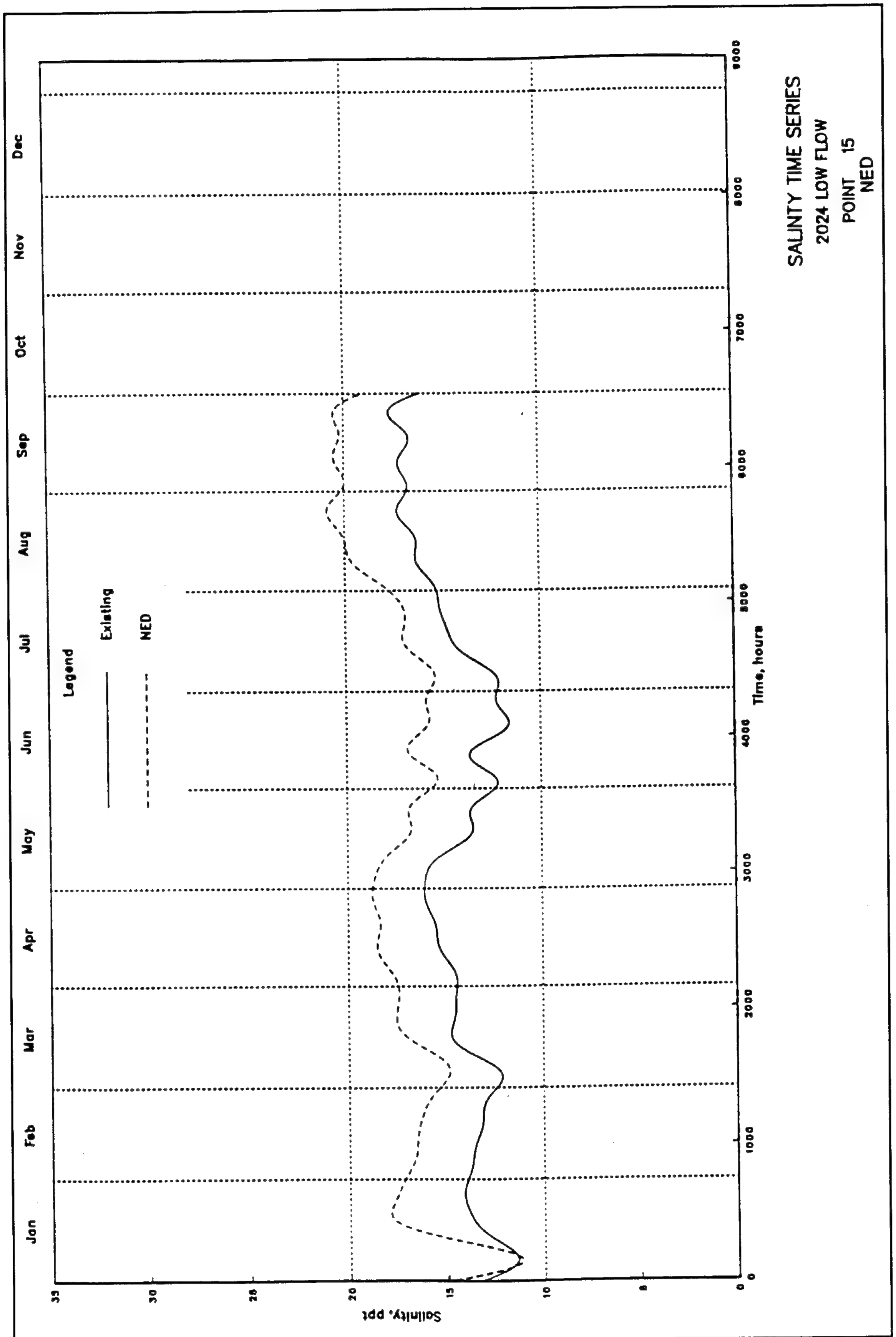
Plate 174



SALINTY TIME SERIES
2024 LOW FLOW
POINT 15
NED
Legend
Existing
NED
Salinity, ppt
Time, hours
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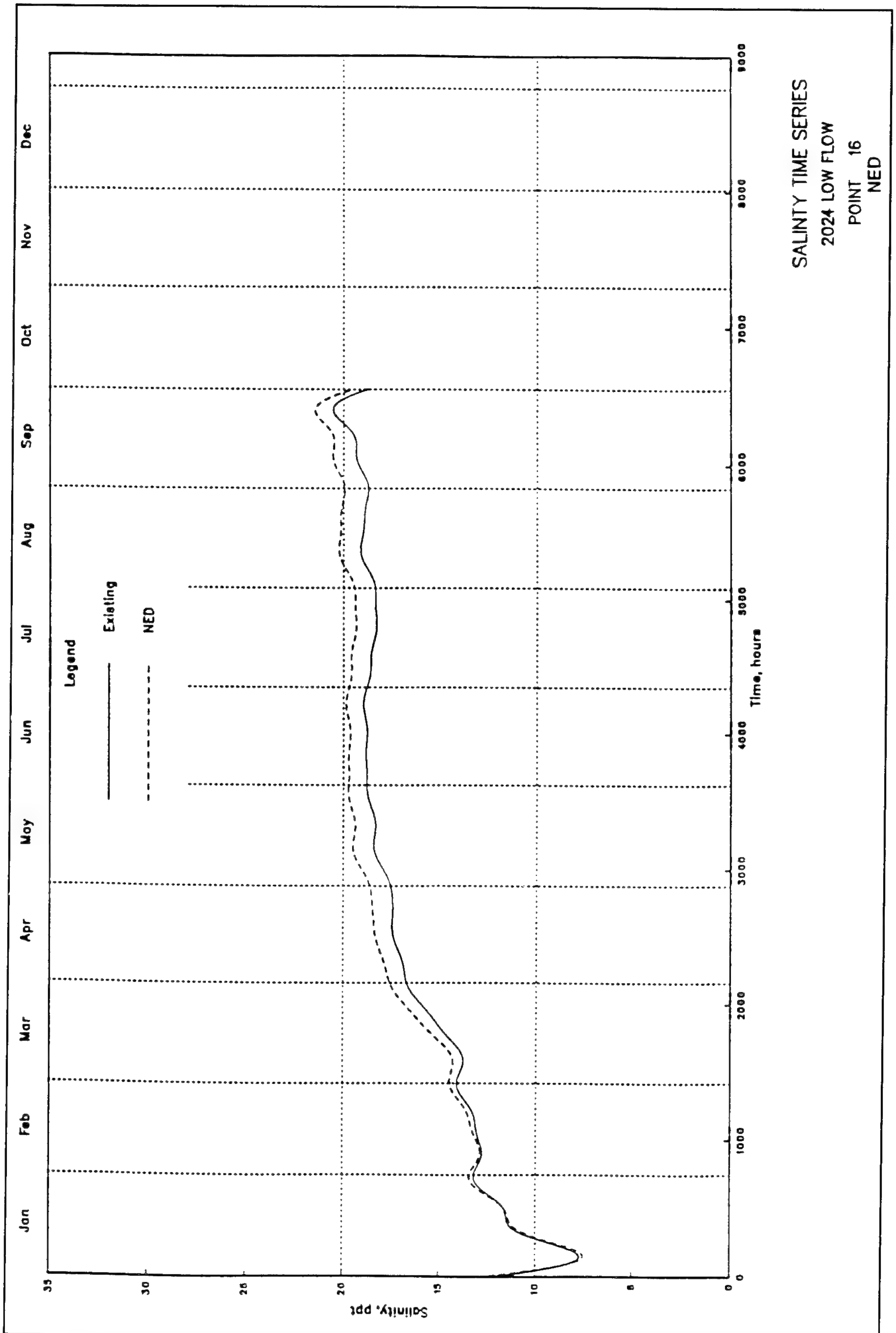
SALINITY TIME SERIES
2024 LOW FLOW
POINT 16
NED
Legend
Existing
NED
Salinity, ppt
Time, hours
Jan
Feb
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May
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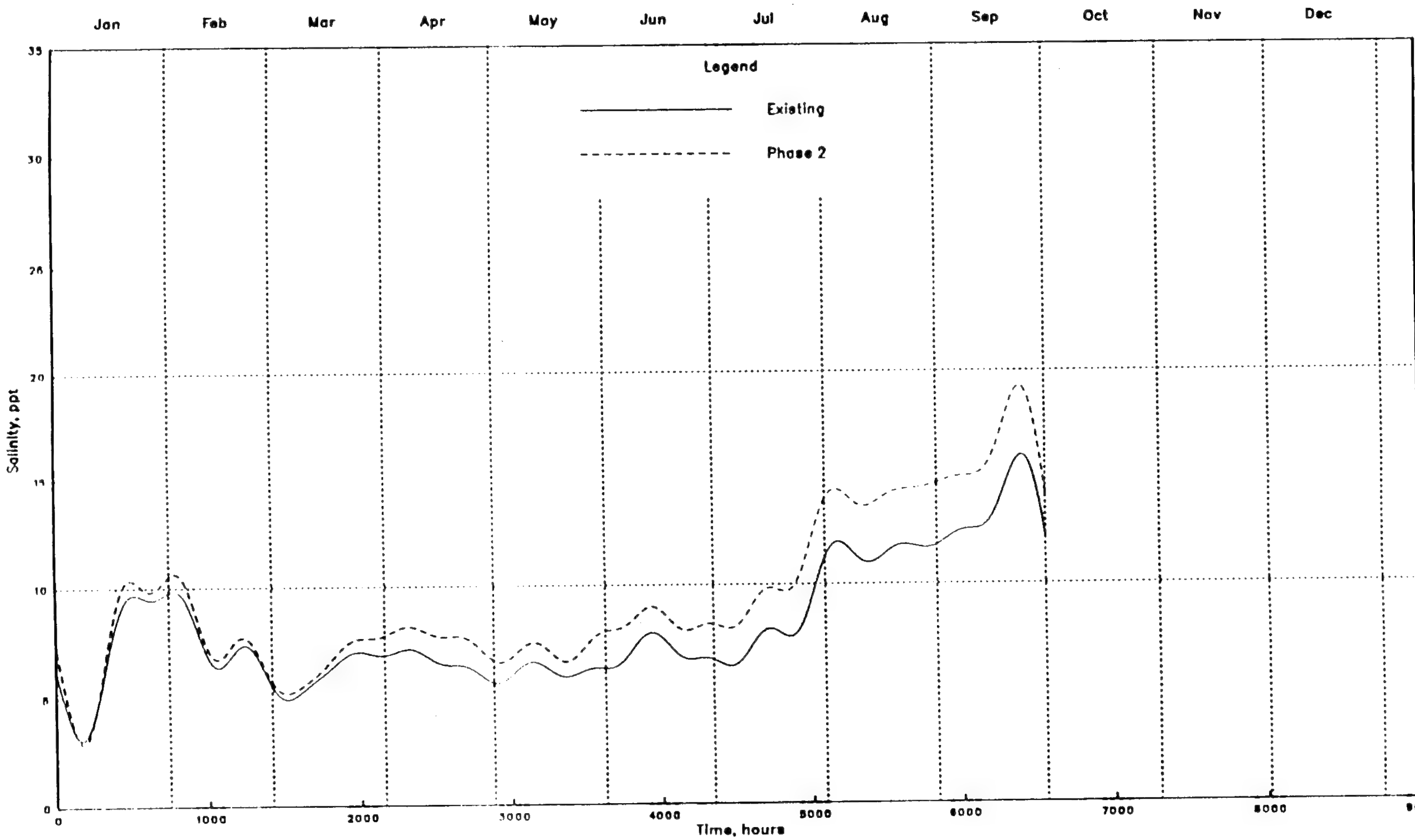
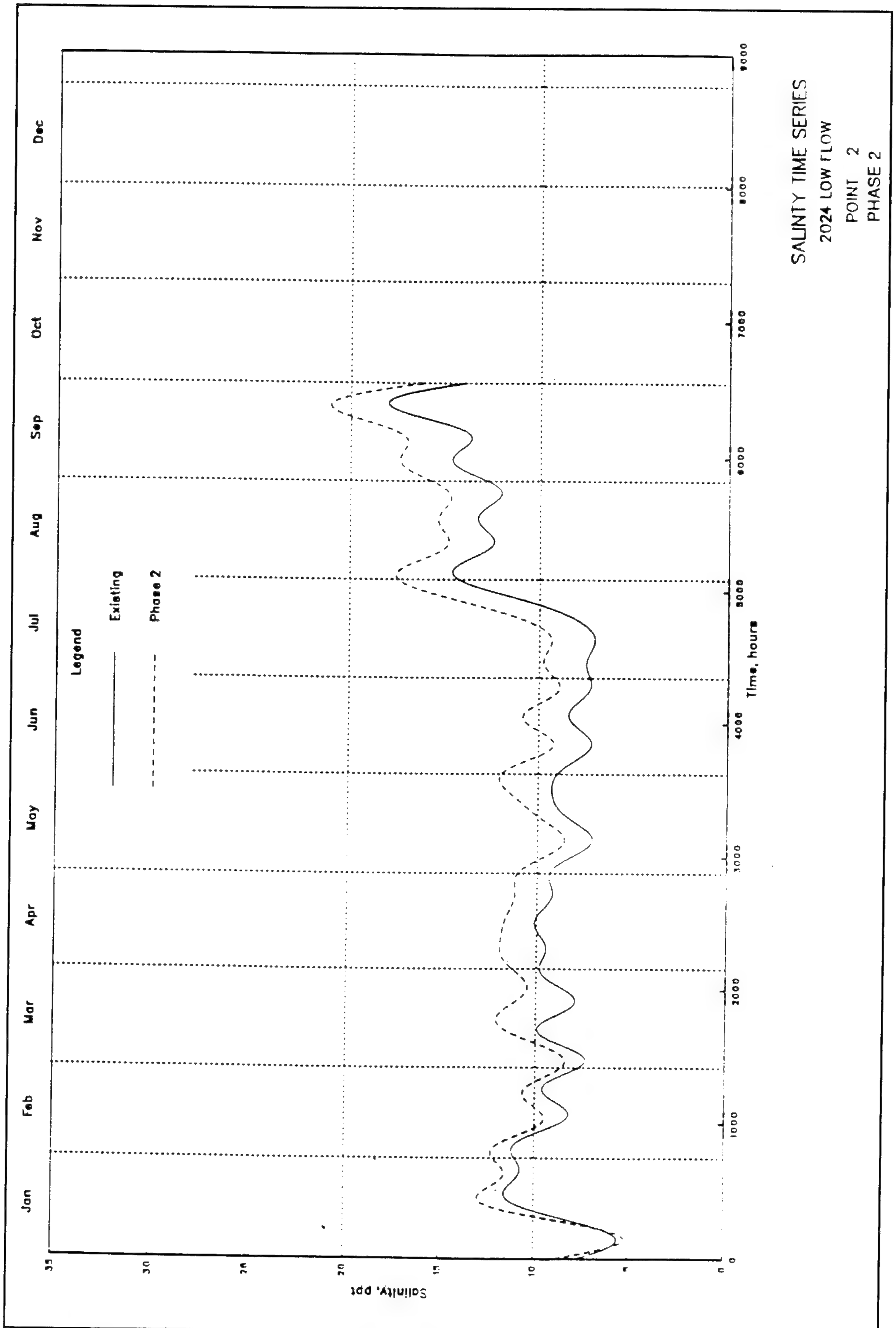


SALINTY TIME SERIES
2024 LOW FLOW
POINT 1
PHASE 2



SALINITY TIME SERIES
2024 LOW FLOW
POINT 2
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
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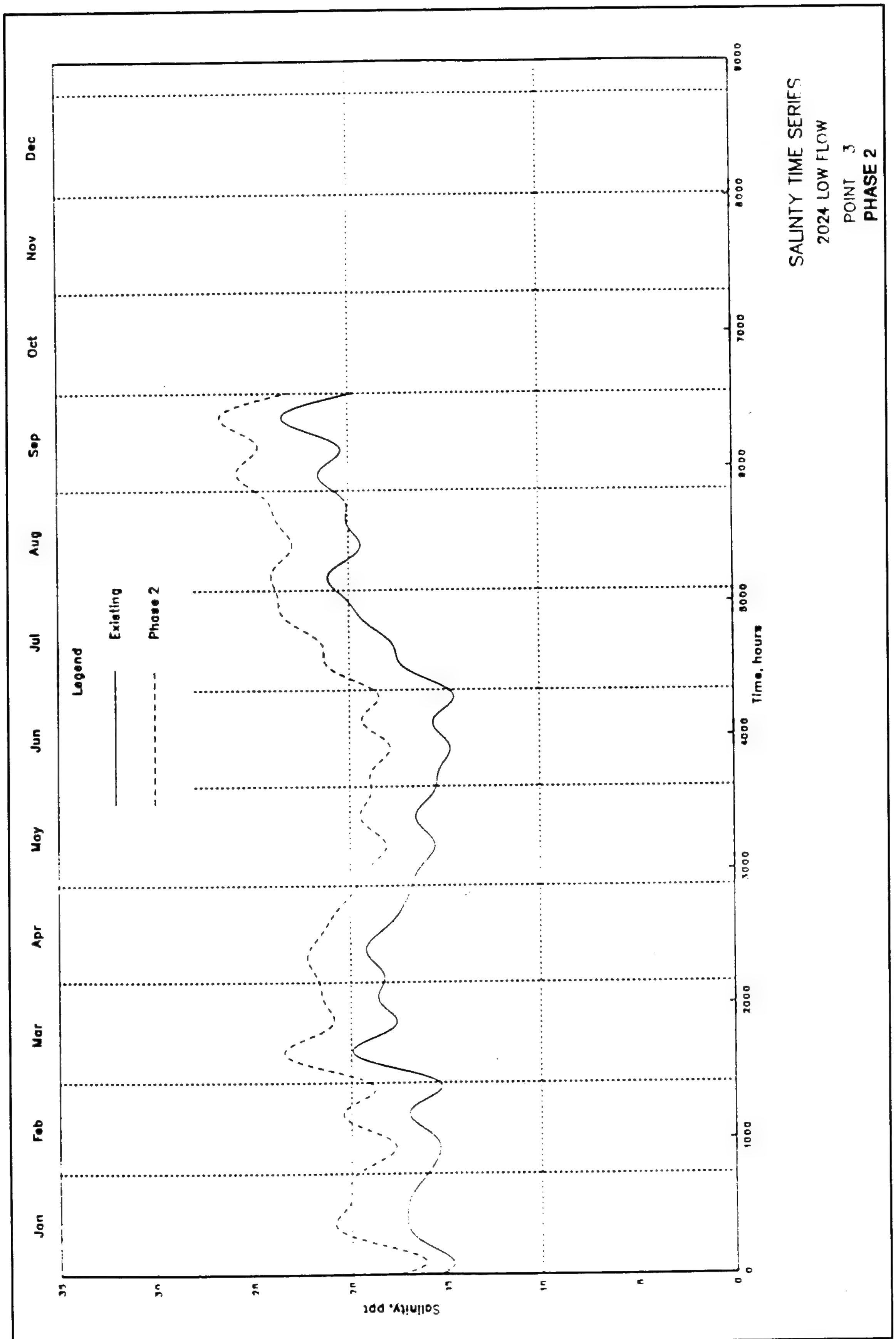
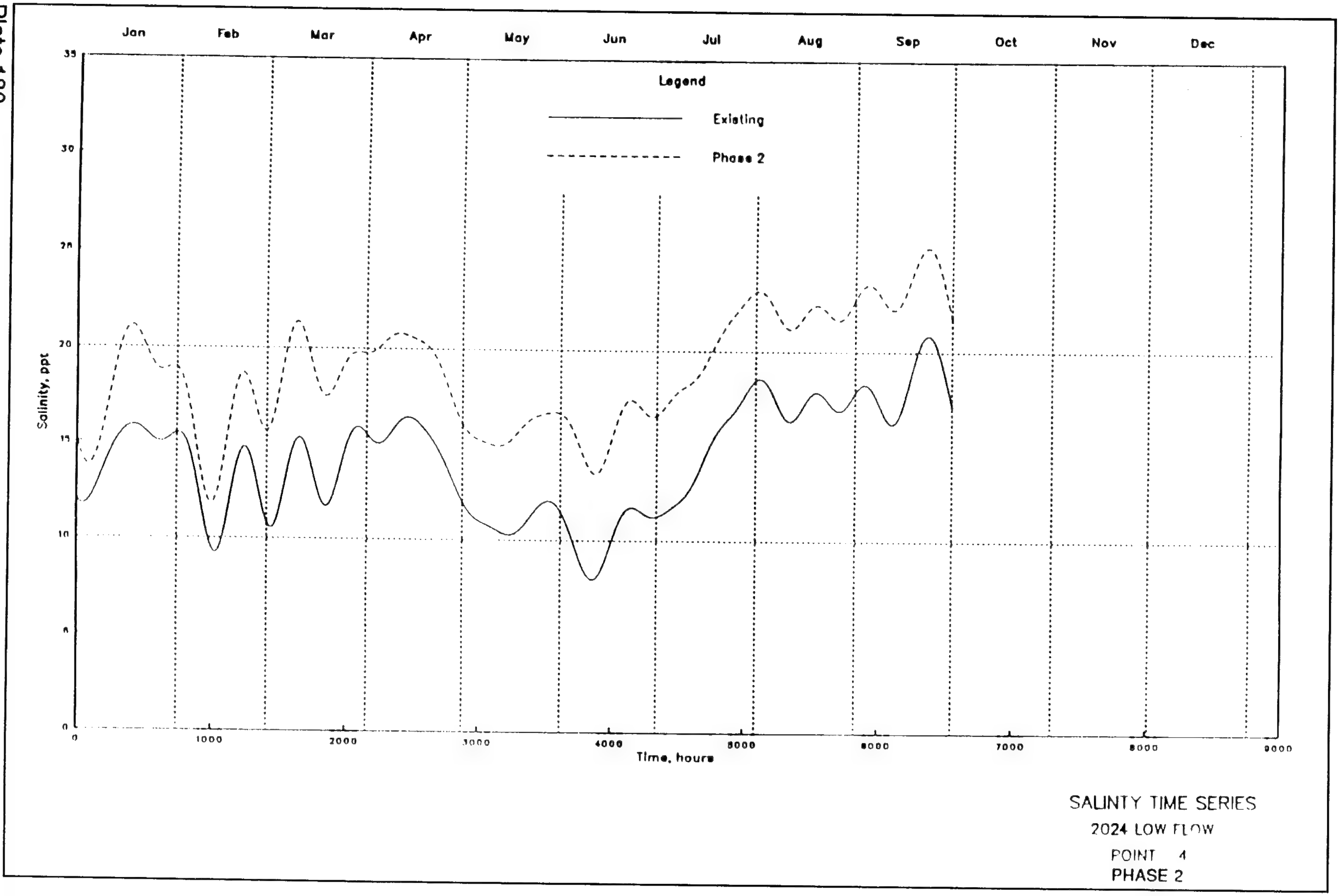
Oct
Nov
Dec

Plate 178



SALINTY TIME SERIES
2024 LOW FLOW
POINT 3
PHASE 2
Legend
Existing
Phase 2
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Time, hours
Salinity, ppt


Jan
Feb
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May
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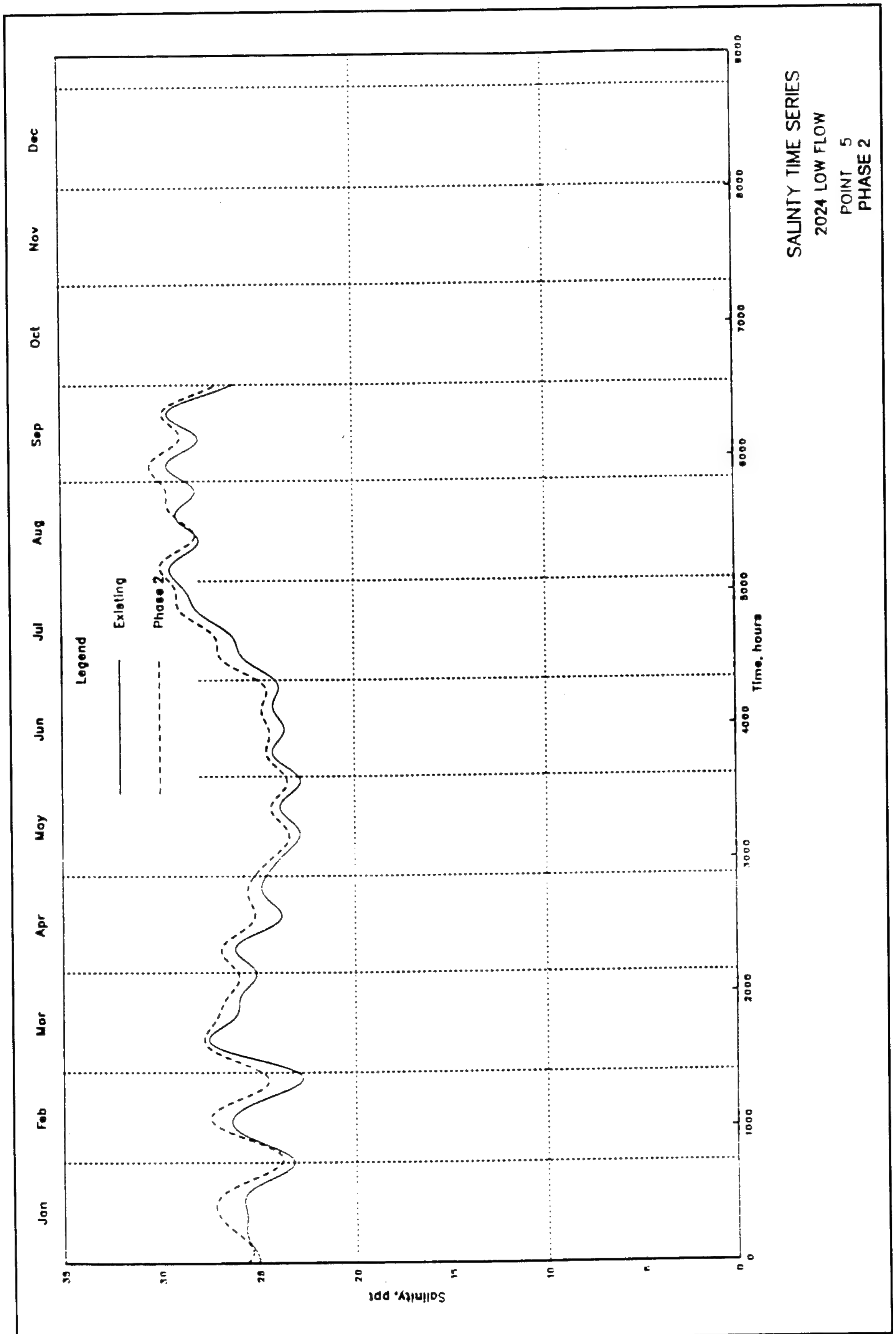
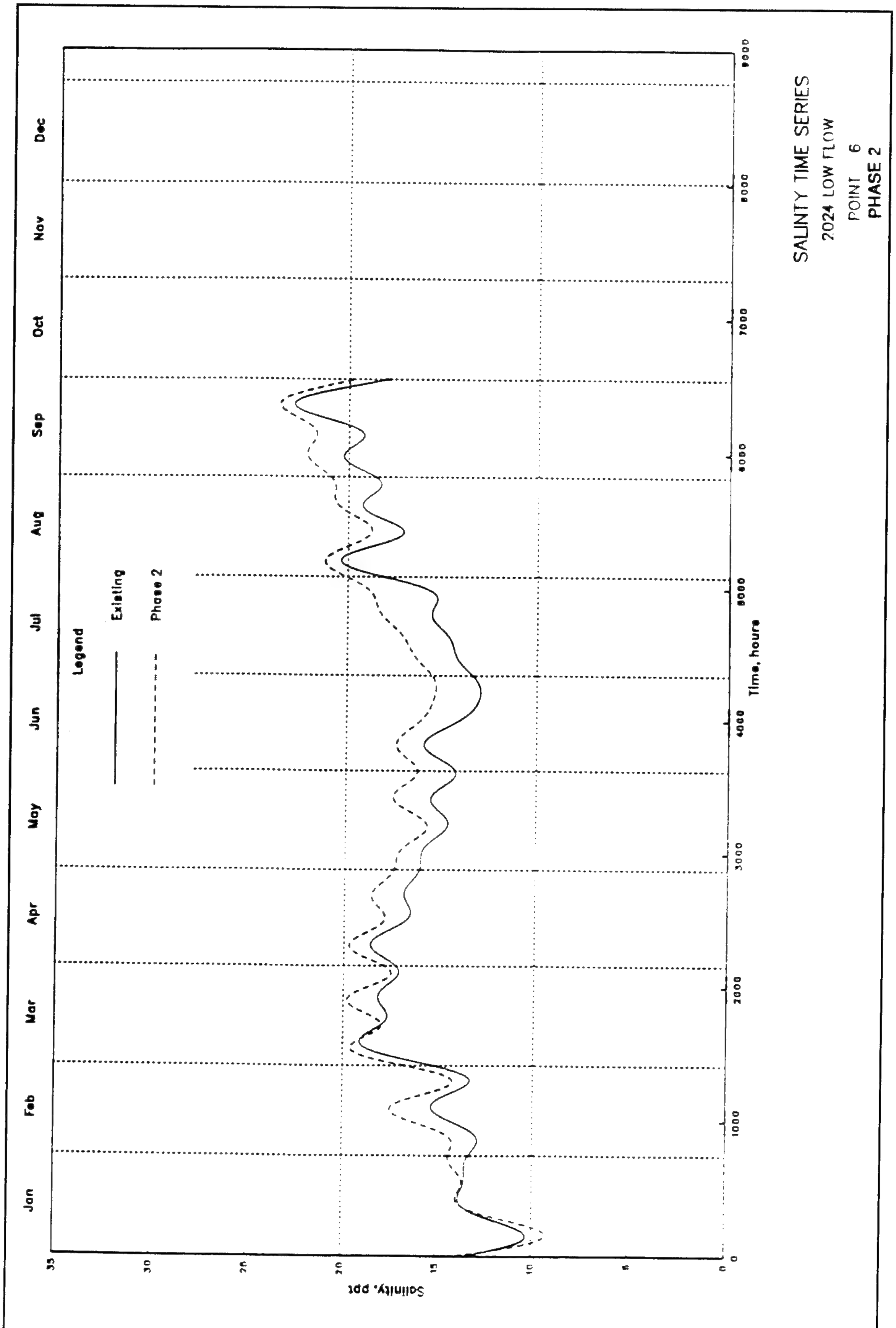
Sep
Oct
Nov
Dec
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
SALINTY TIME SERIES
2024 LOW FLOW
POINT 4
PHASE 2



SALINTY TIME SERIES
2024 LOW FLOW
POINT 5
PHASE 2


SALINTY TIME SERIES
2024 LOW FLOW
POINT 6
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
Jan
Feb
Mar
Apr
May
Jun
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Nov
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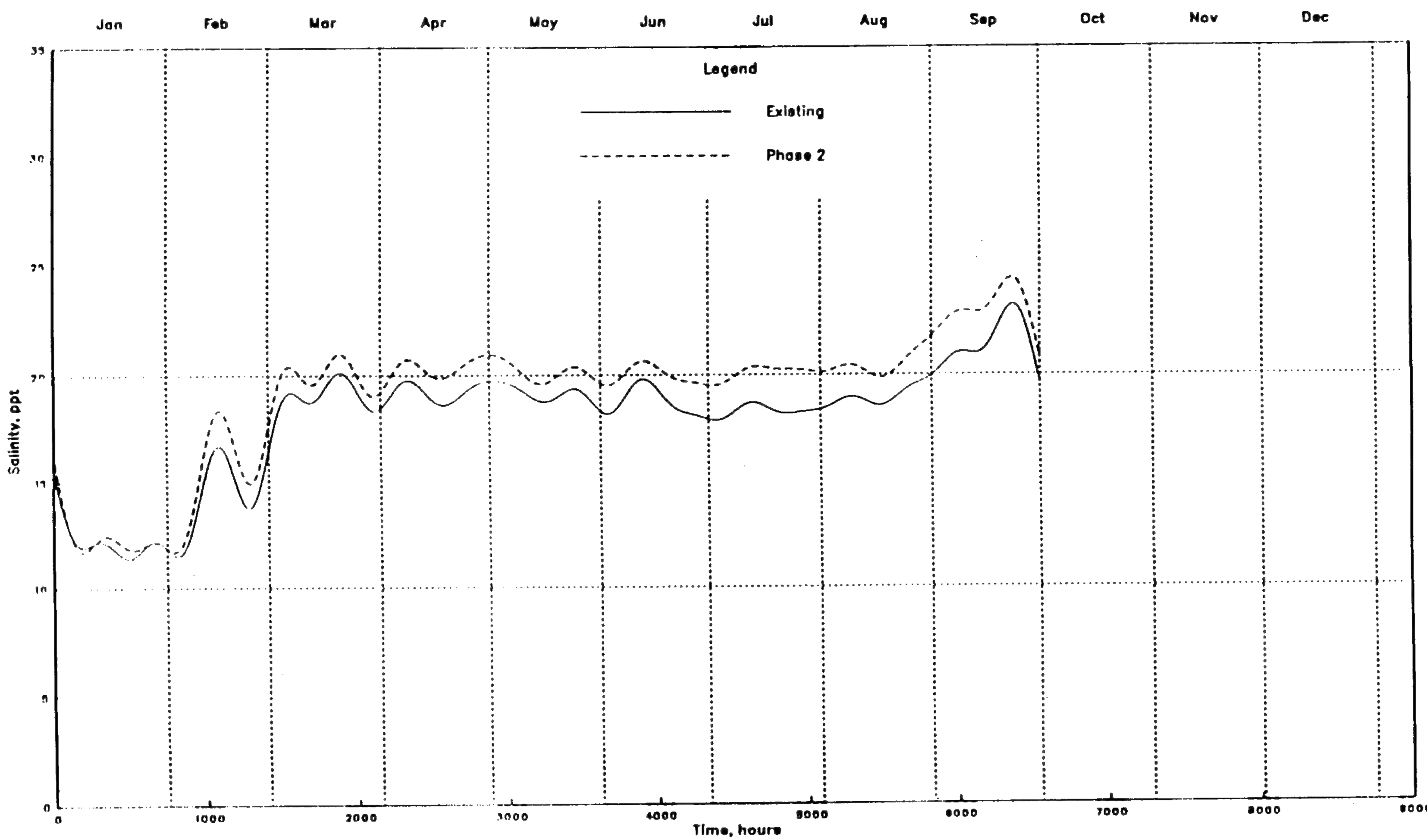
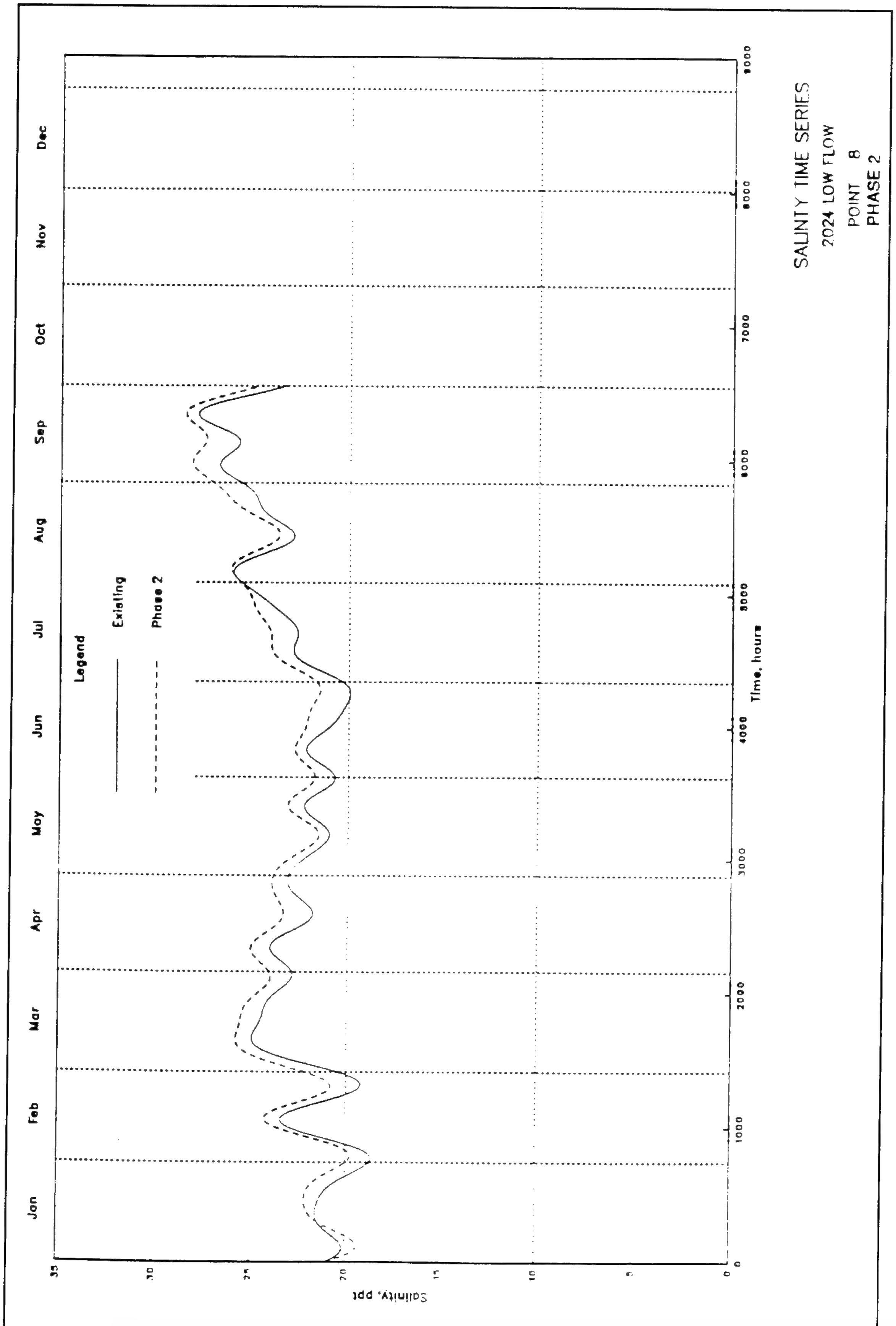


SALINTY TIME SERIES
2024 LOW FLOW
POINT 7
PHASE 2


SALINITY TIME SERIES
2024 LOW FLOW
POINT 8
PHASE 2
Legend
Existing
Phase 2
Jan
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Time, hours
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Salinity, ppt
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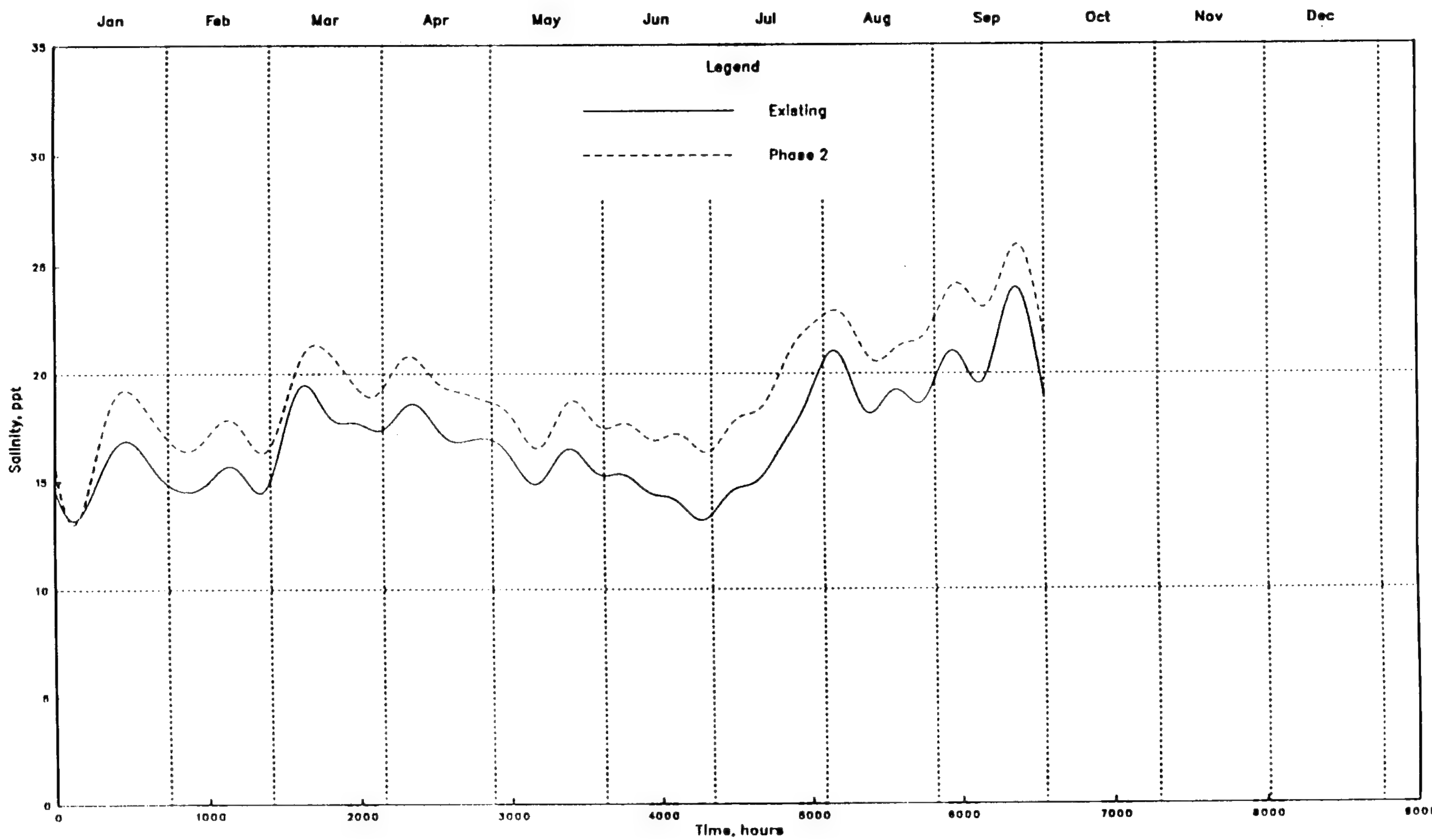
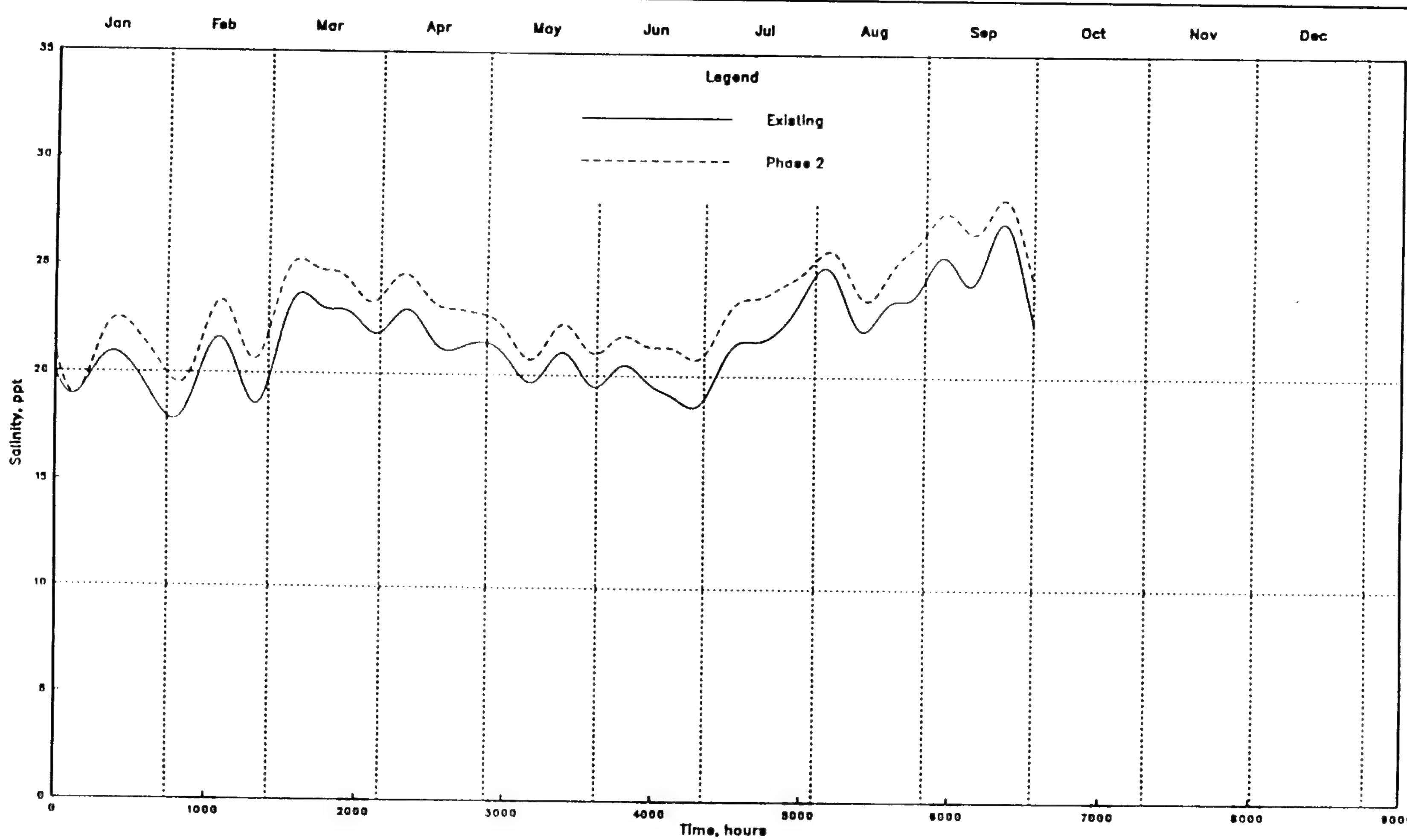
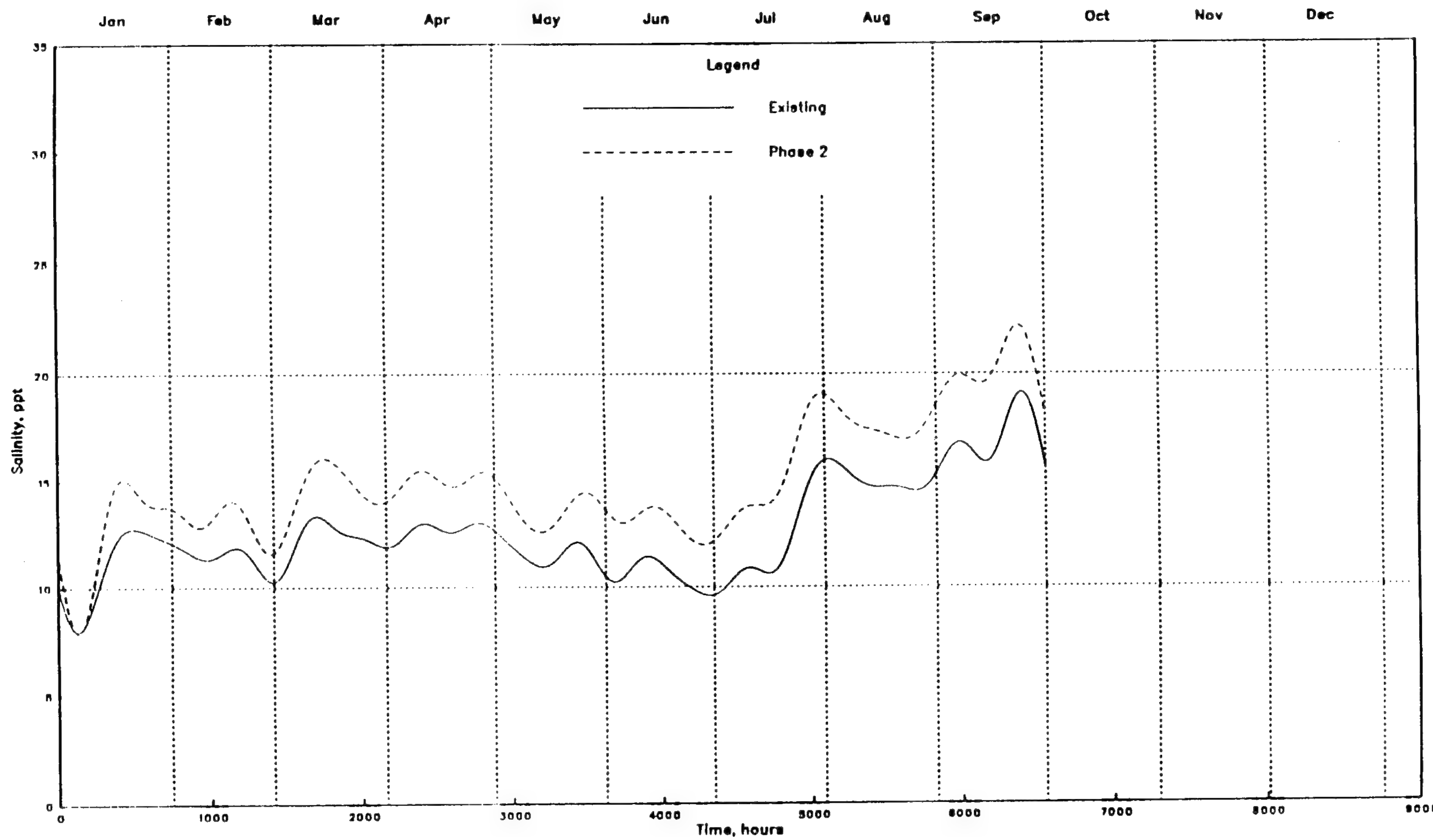
Plate 184



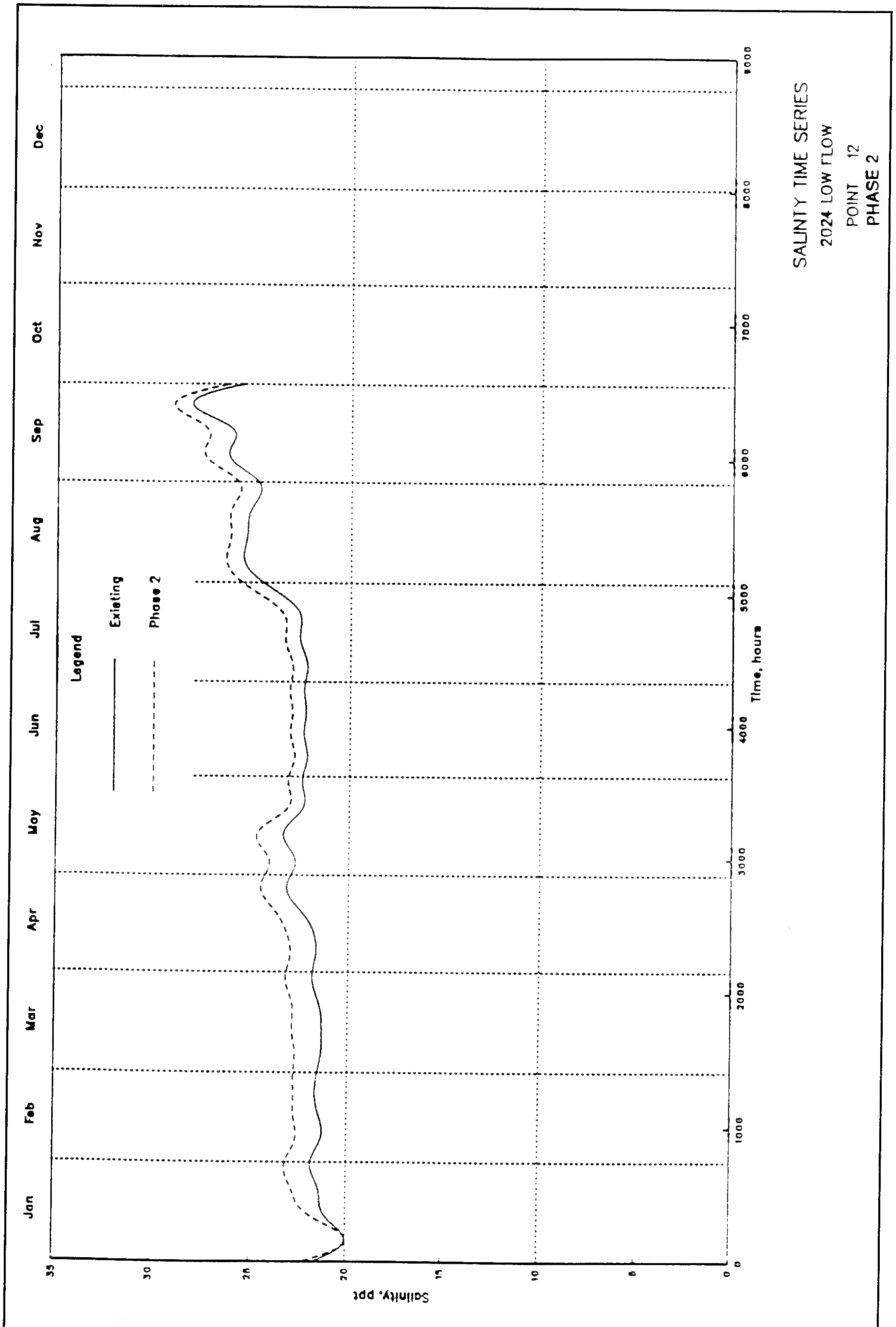
SALINTY TIME SERIES
2024 LOW FLOW
POINT 9
PHASE 2



SALINTY TIME SERIES
2024 LOW FLOW
POINT 10
PHASE 2



SALINTY TIME SERIES
2024 LOW FLOW
POINT 11
PHASE 2


SALINTY TIME SERIES
2024 LOW FLOW
POINT 12
PHASE 2
Legend
Existing
Phase 2
Jan
Feb
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Salinity, ppt
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Time, hours
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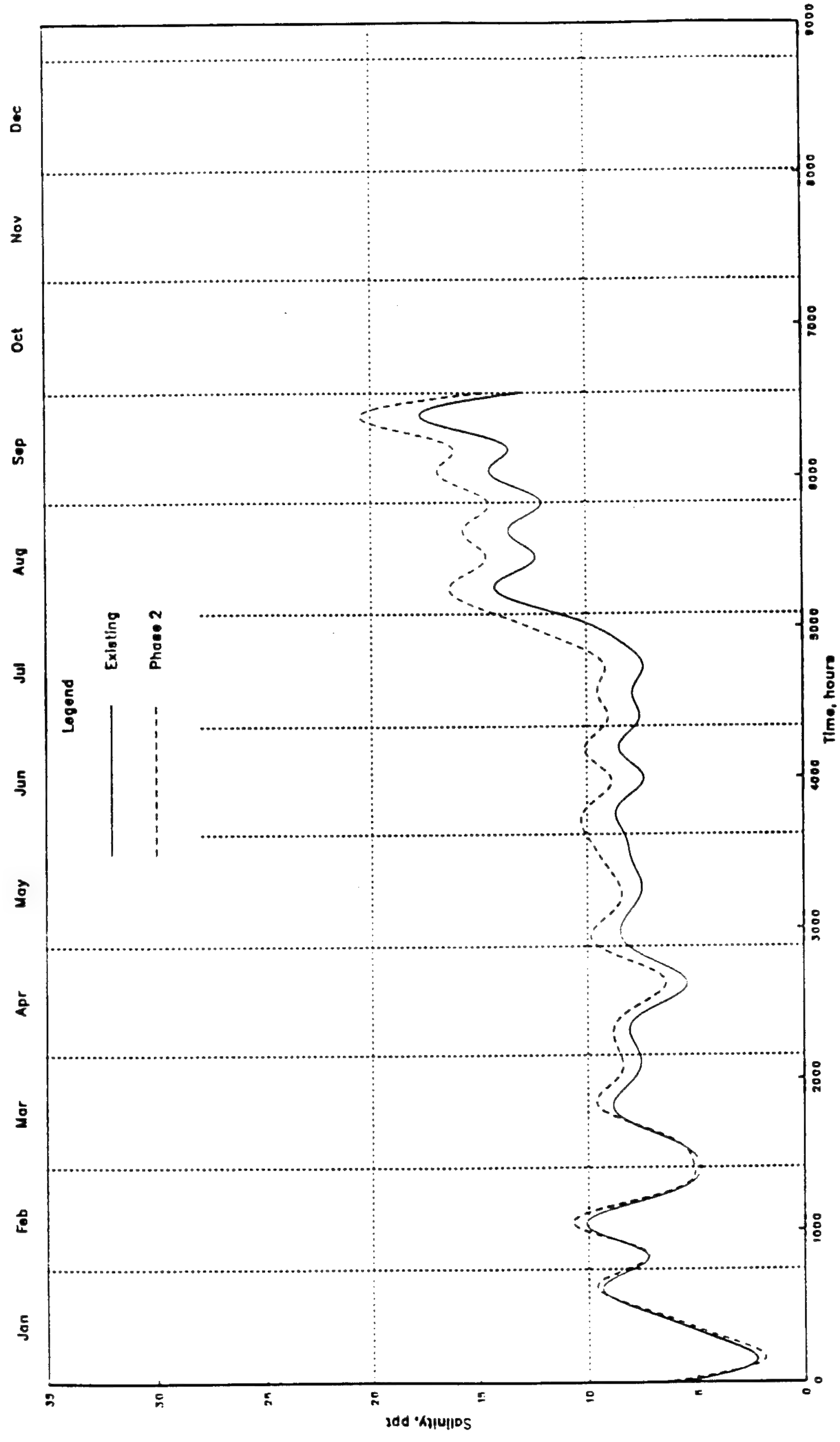
Plate 188



SALINTY TIME SERIES
2024 LOW FLOW
POINT 13
PHASE 2

Plate 189

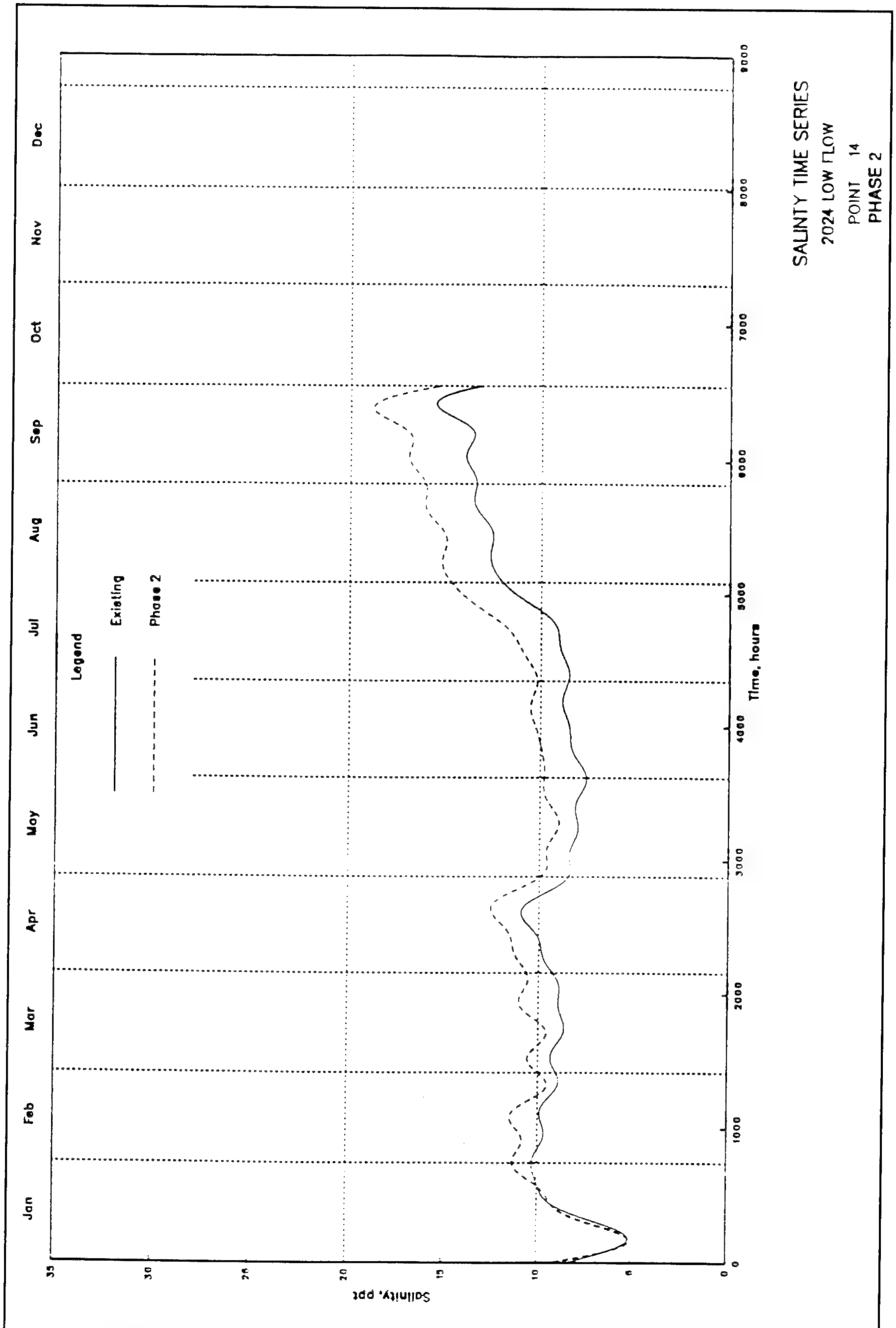

SALINTY TIME SERIES
2024 LOW FLOW
POINT 14
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
Jan
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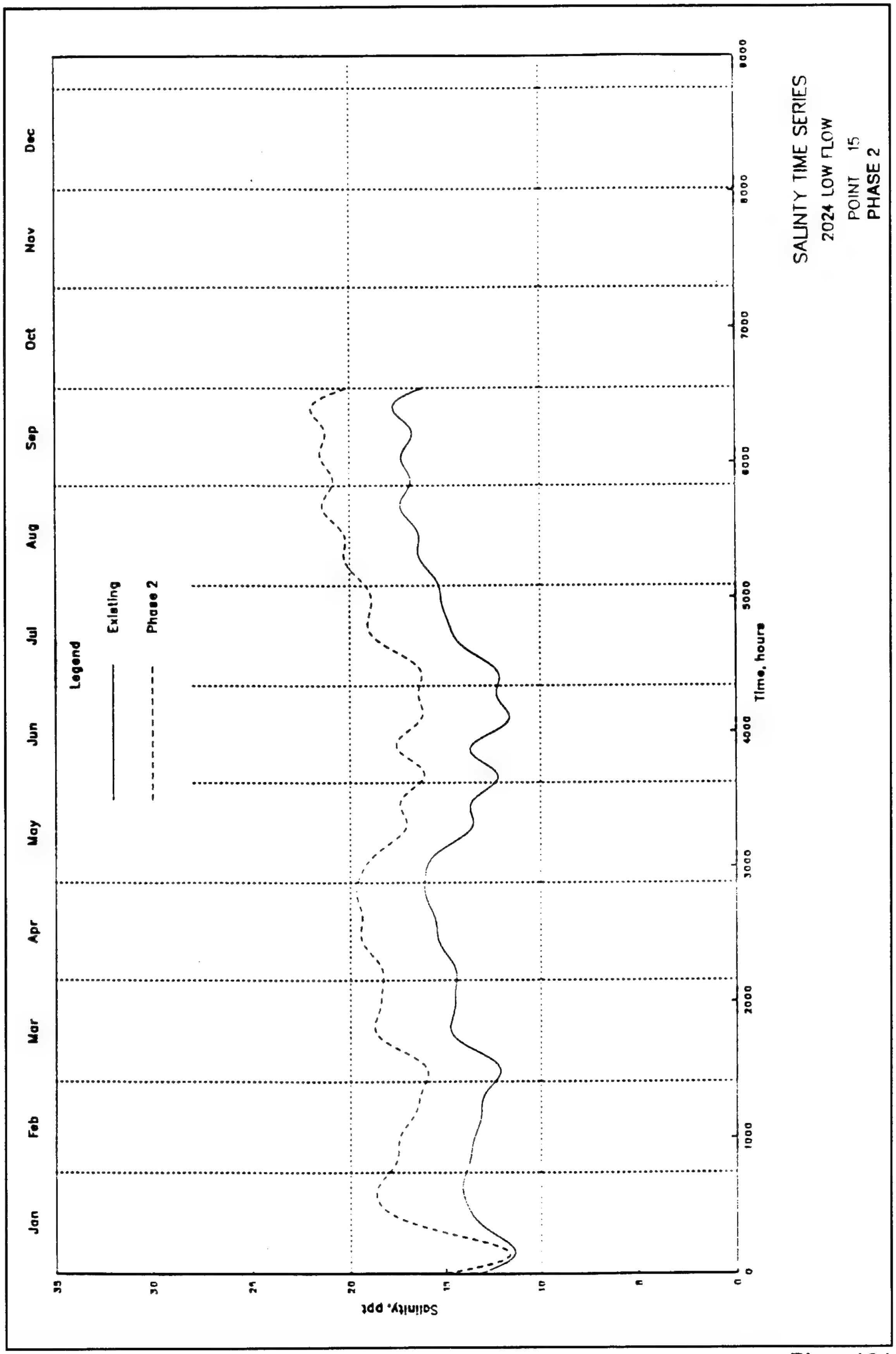
Plate 190


SALINTY TIME SERIES
2024 LOW FLOW
POINT 15
PHASE 2
Legend
Existing
Phase 2
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Salinity, ppt
Time, hours
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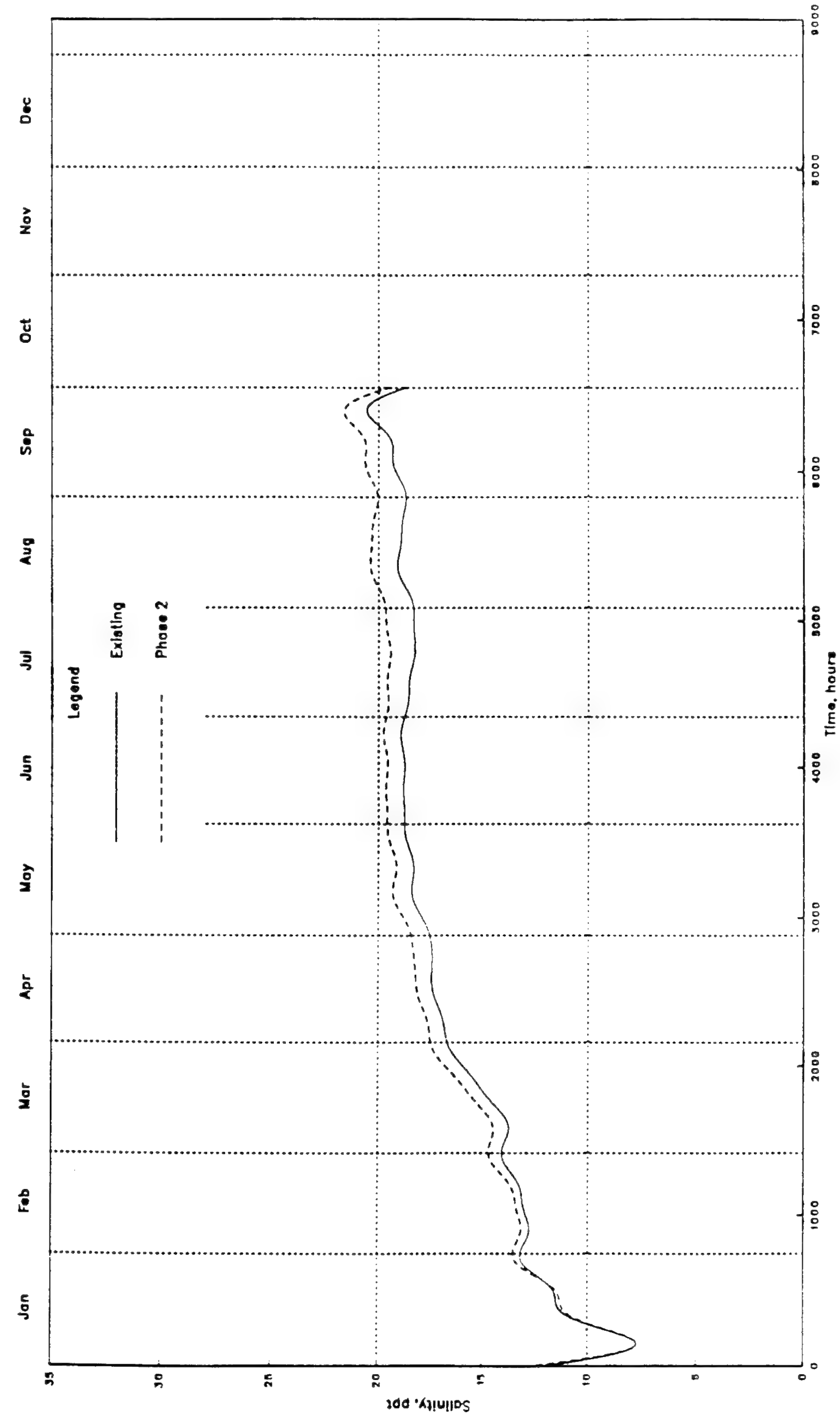

SALINTY TIME SERIES
2024 LOW FLOW
POINT 16
PHASE 2

Plate 192

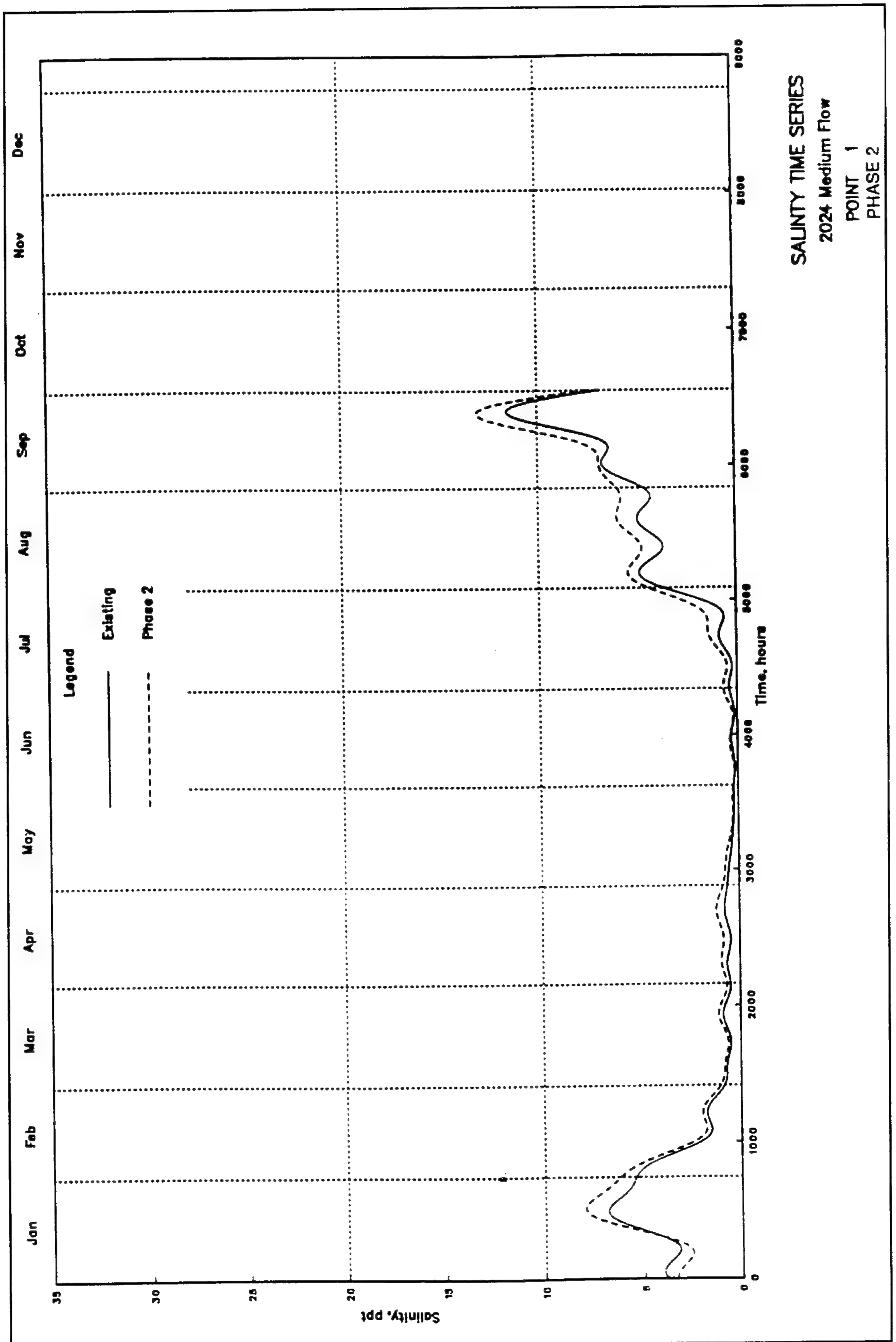
SALINTY TIME SERIES
2024 Medium Flow
POINT 1
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
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Plate 193

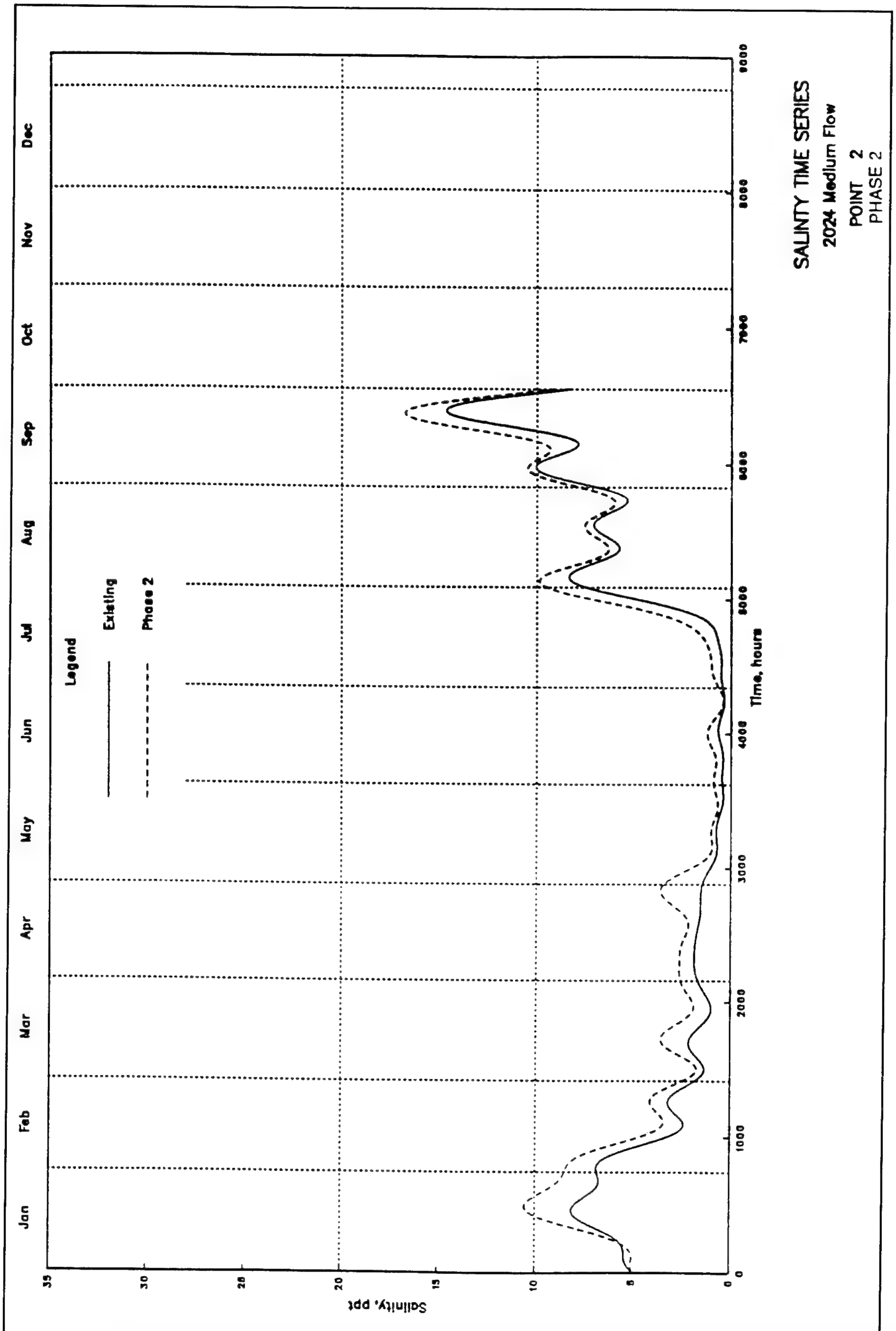
SALINTY TIME SERIES
2024 Medium Flow
POINT 2
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
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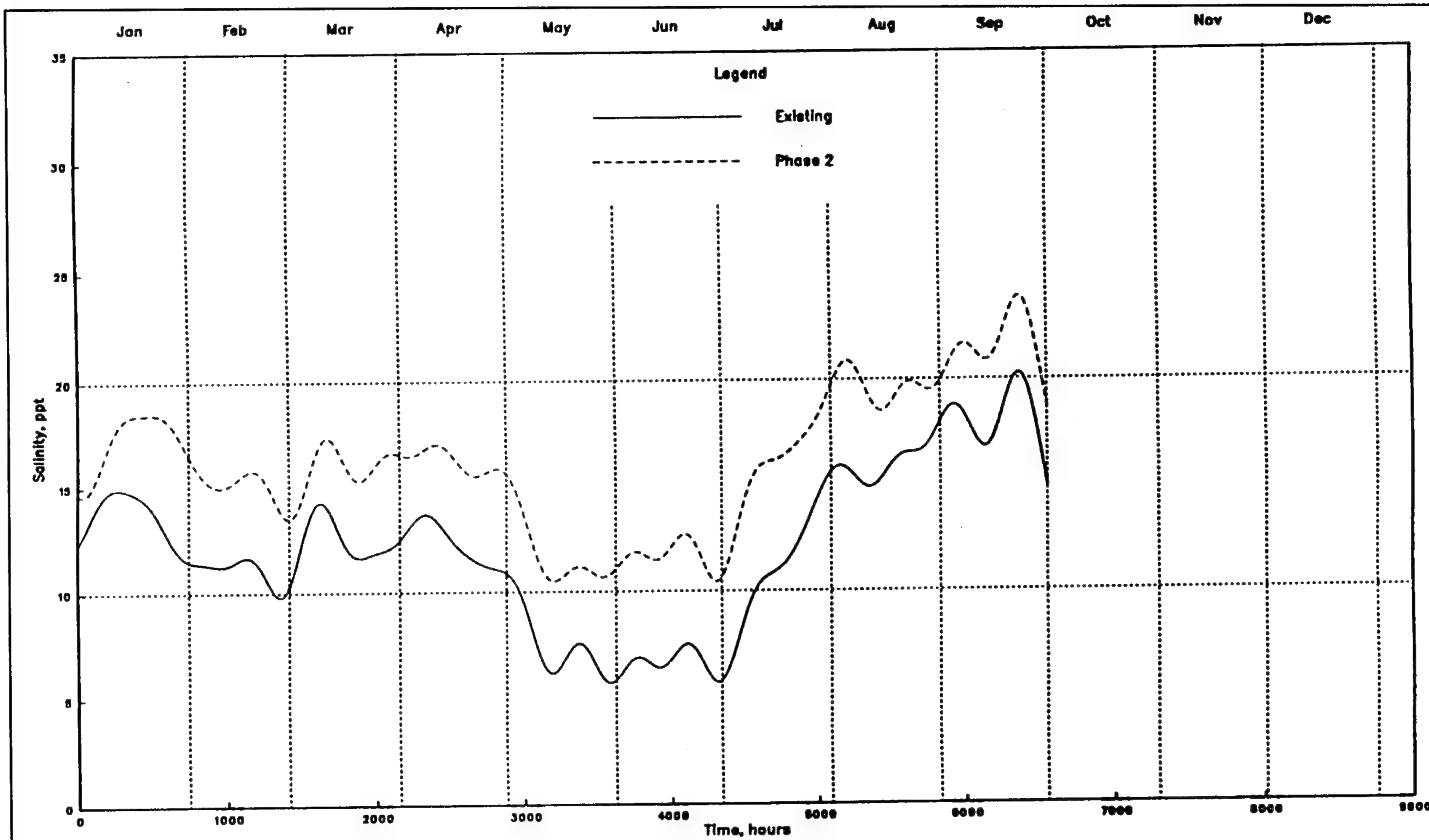
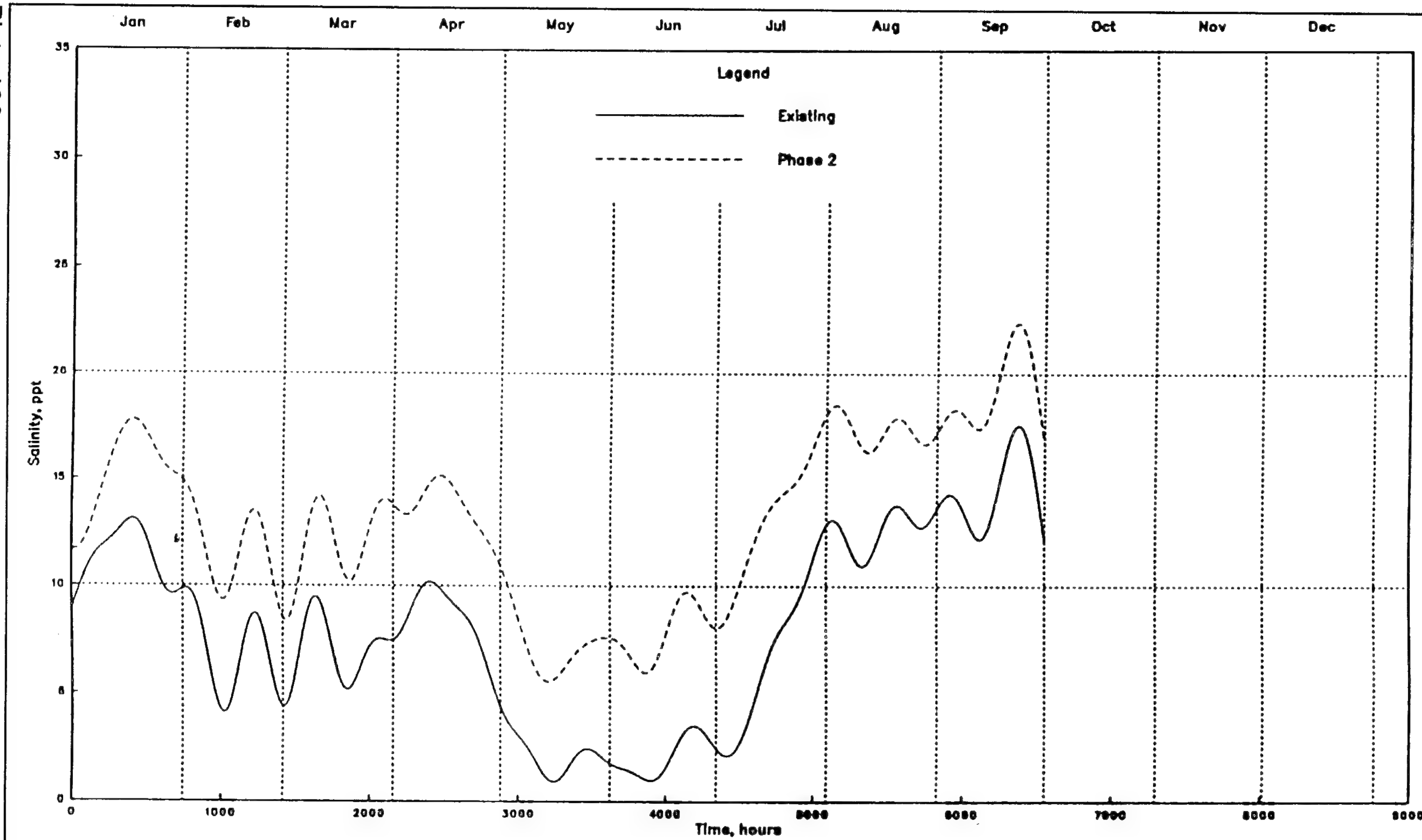
Plate 194

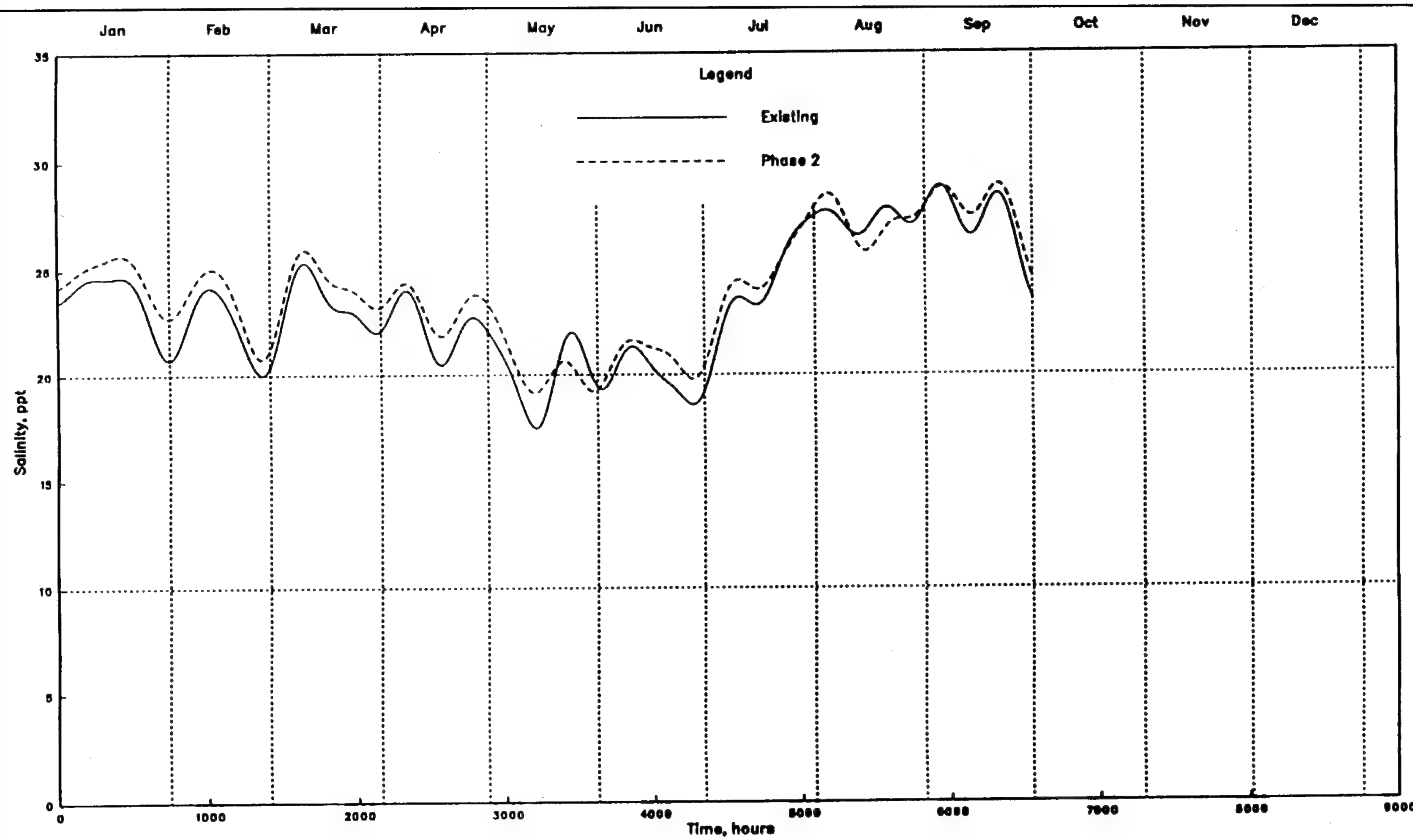


SALINTY TIME SERIES
2024 Medium Flow
POINT 3
PHASE 2

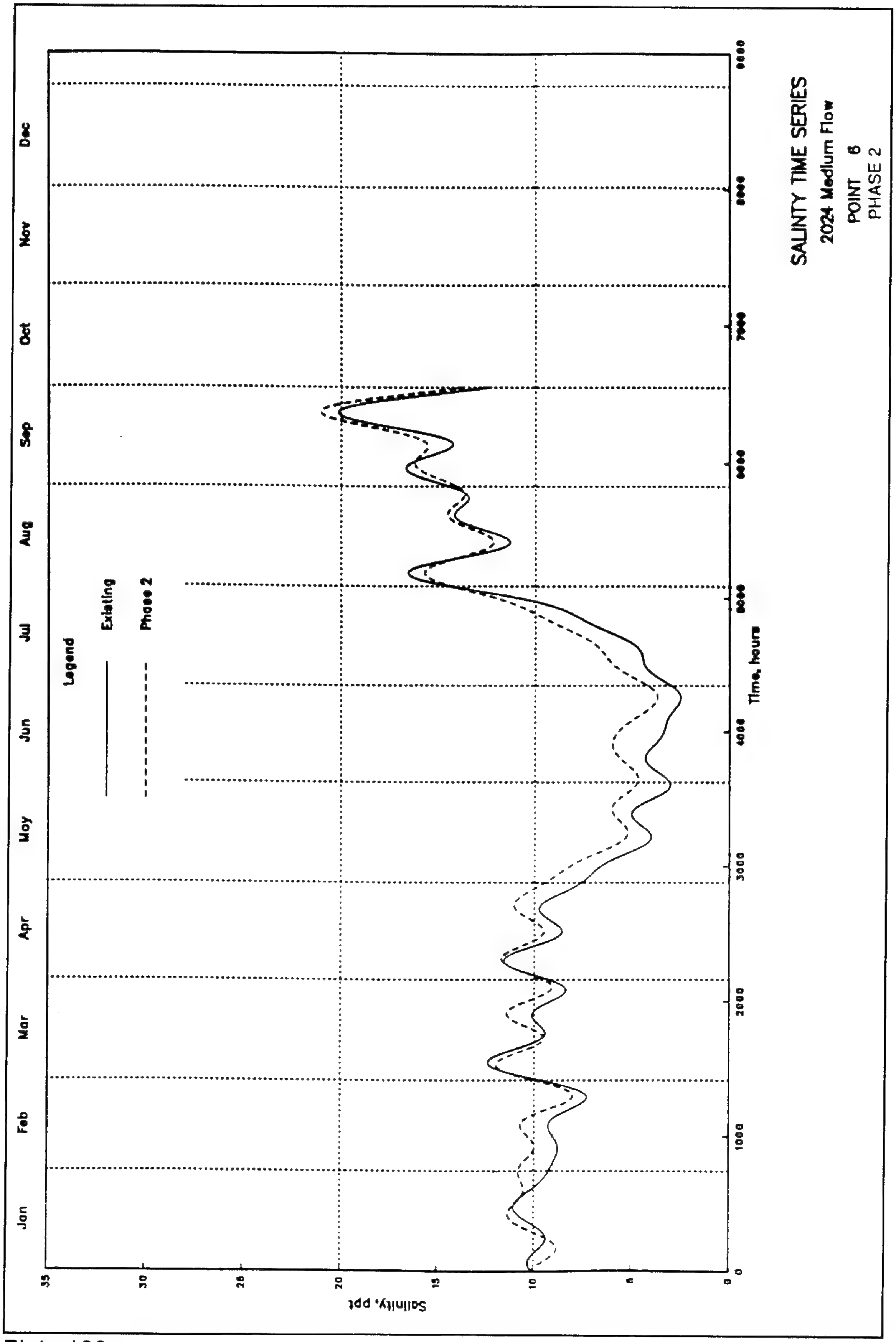


SALINTY TIME SERIES
2024 Medium Flow
POINT 4
PHASE 2

Plate 196



SALINTY TIME SERIES
2024 Medium Flow
POINT 5
PHASE 2


SALINITY TIME SERIES
2024 Medium Flow
POINT 6
PHASE 2
Legend
Existing
Phase 2
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Salinity, ppt
Time, hours
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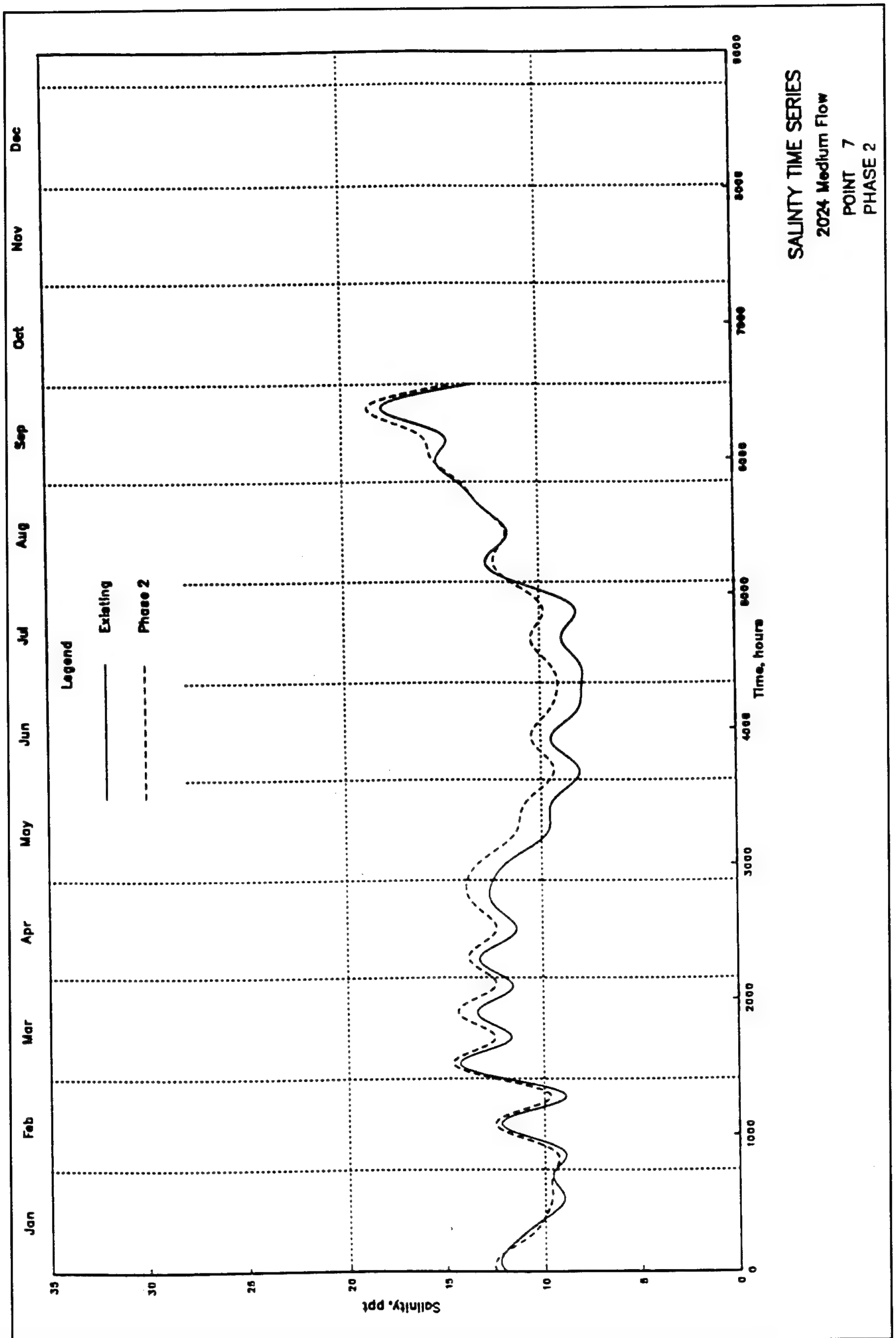
Plate 198


SALINTY TIME SERIES
2024 Medium Flow
POINT 7
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
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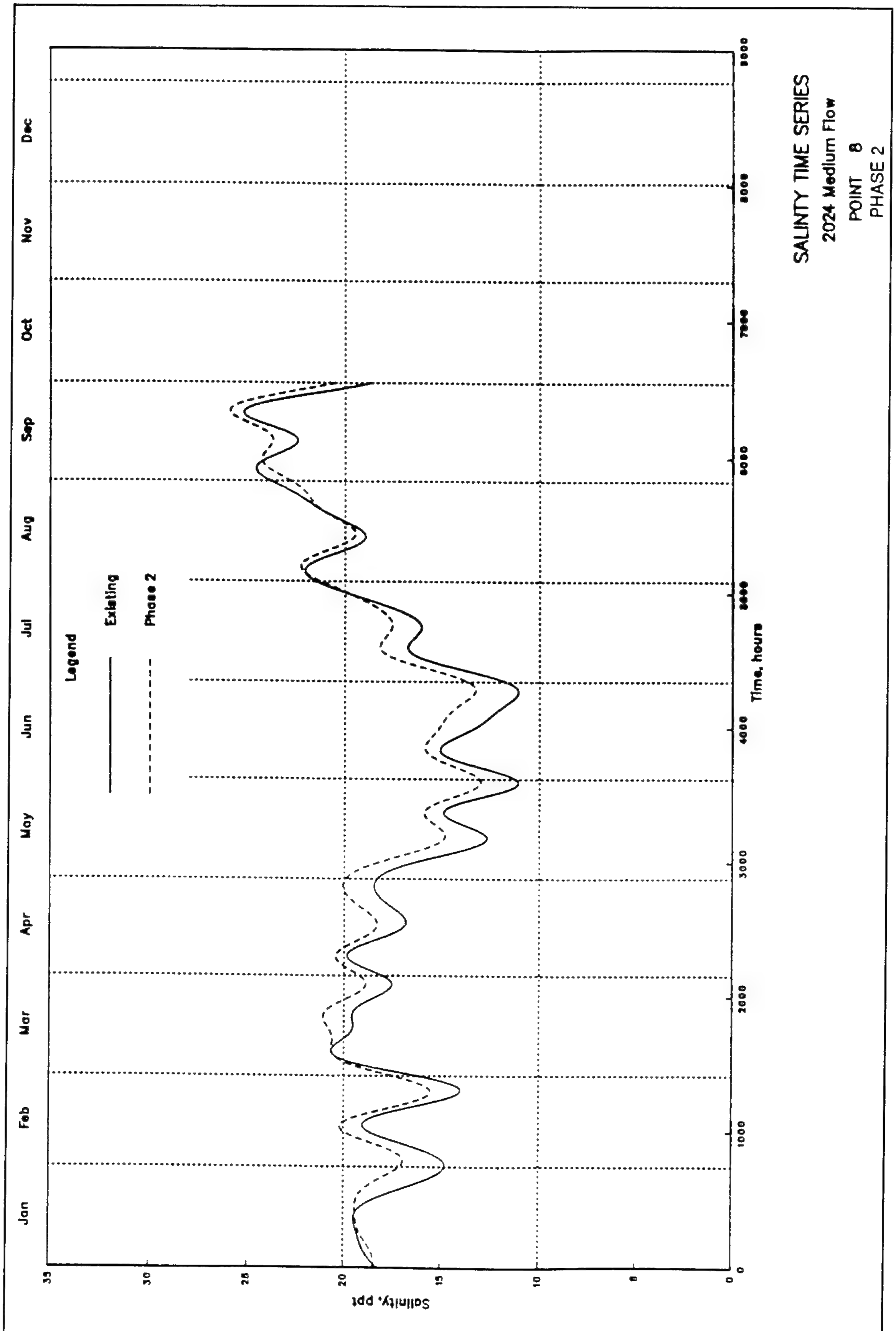

SALINTY TIME SERIES
2024 Medium Flow
POINT 8
PHASE 2
Legend
Existing
Phase 2
Jan
Feb
Mar
Apr
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Jun
Jul
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Sep
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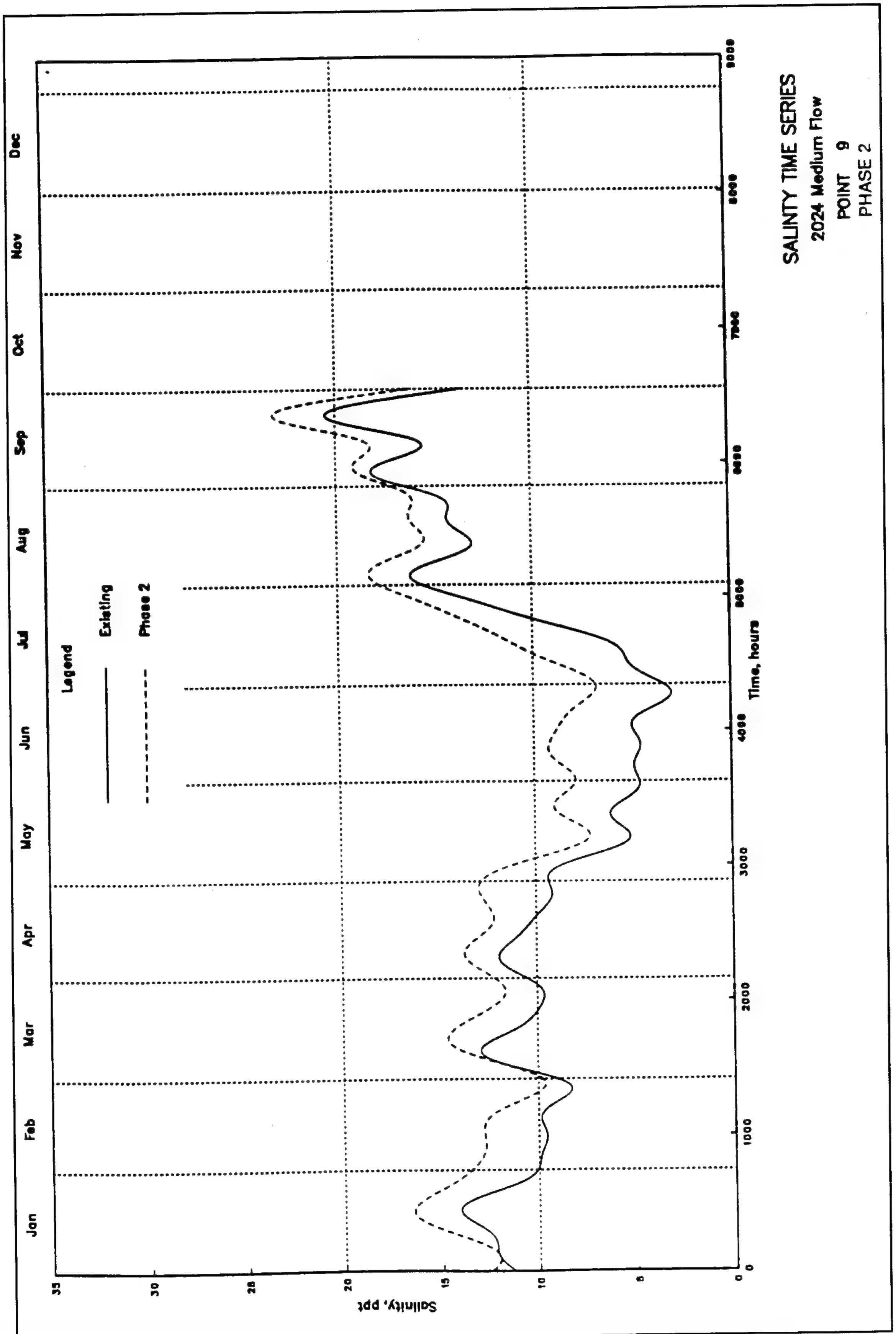
Nov
Dec
Time, hours
Salinity, ppt

Plate 200



SALINTY TIME SERIES
2024 Medium Flow
POINT 9
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
Jan
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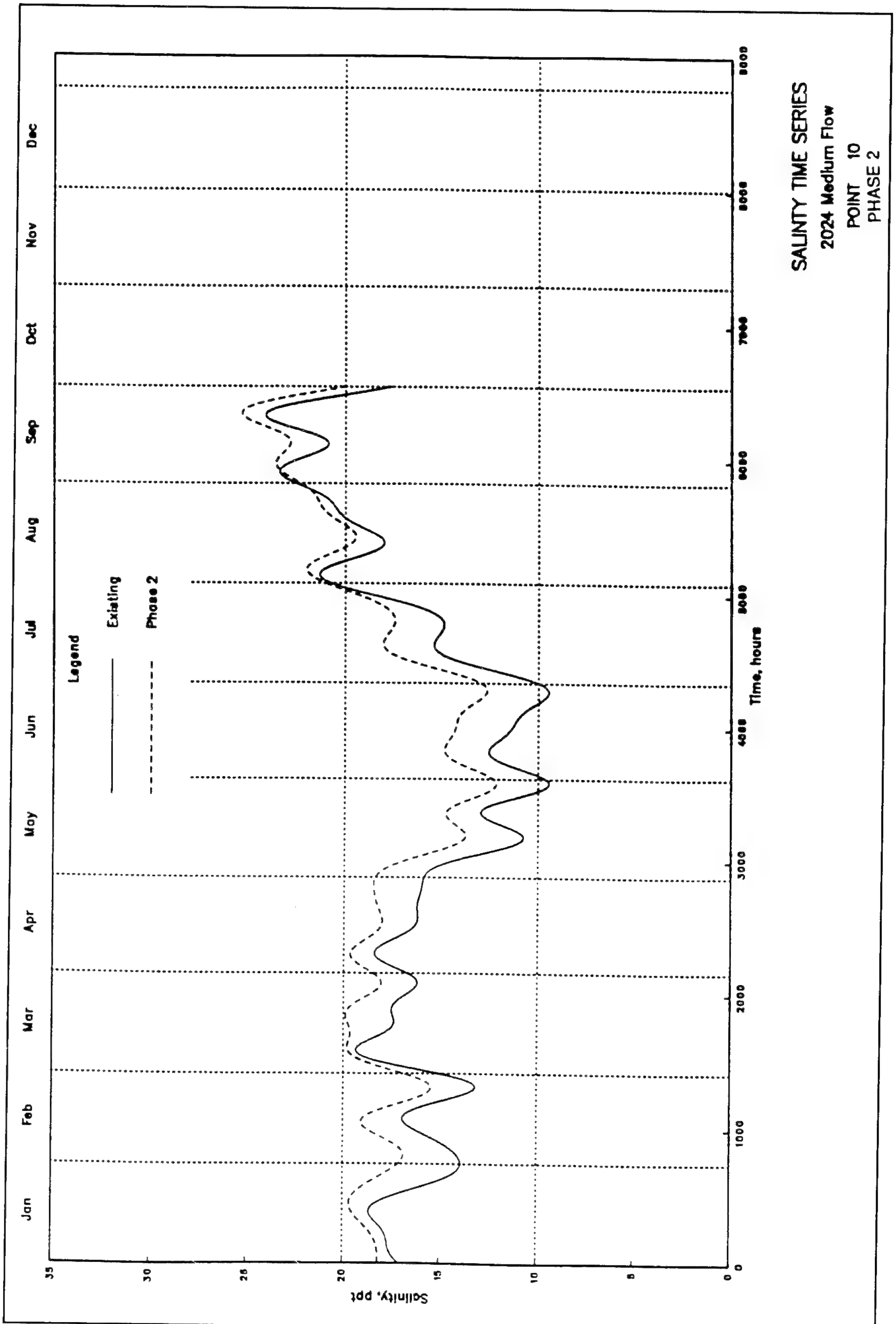
Plate 201



SALINITY TIME SERIES
2024 Medium Flow
POINT 10
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
Jan
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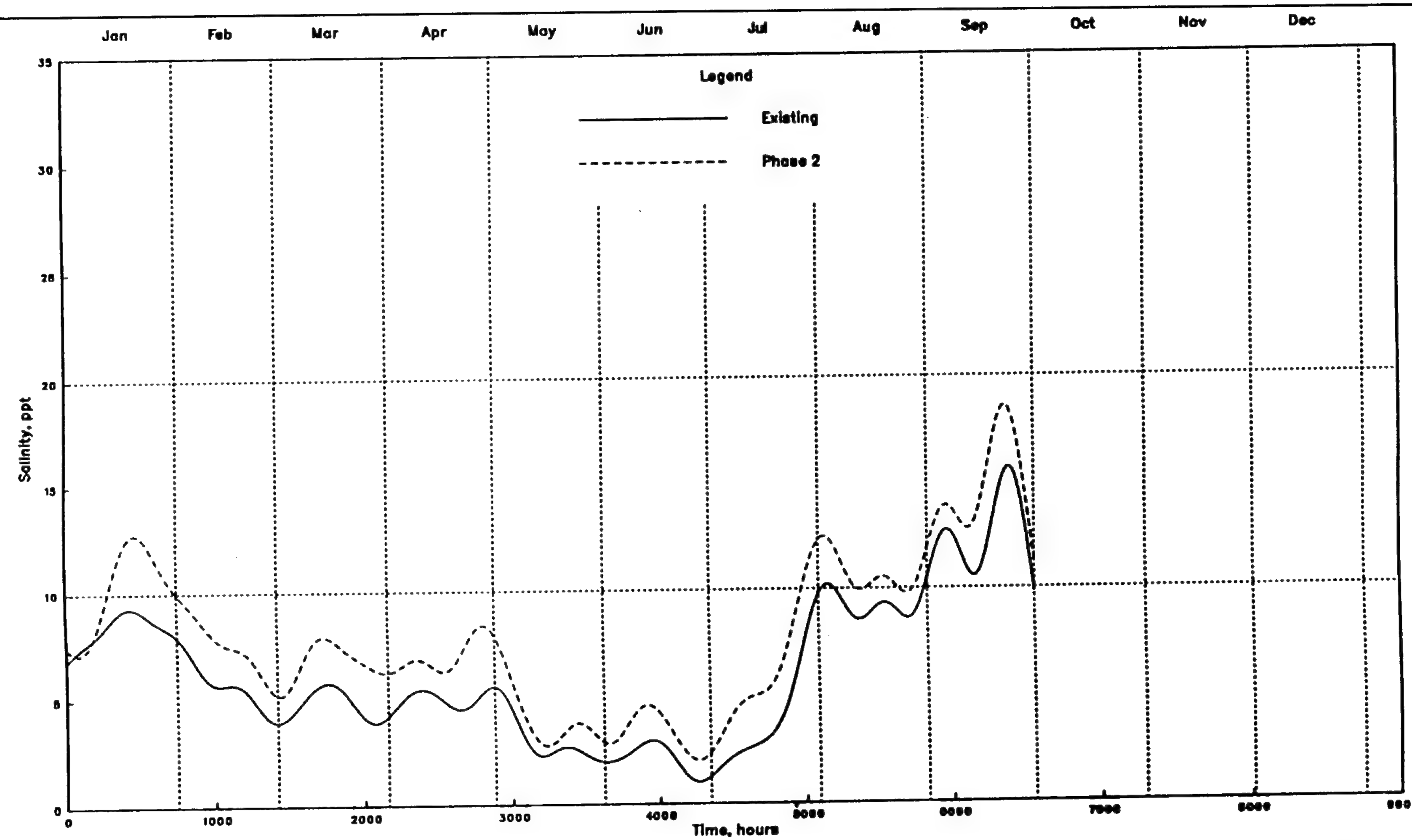
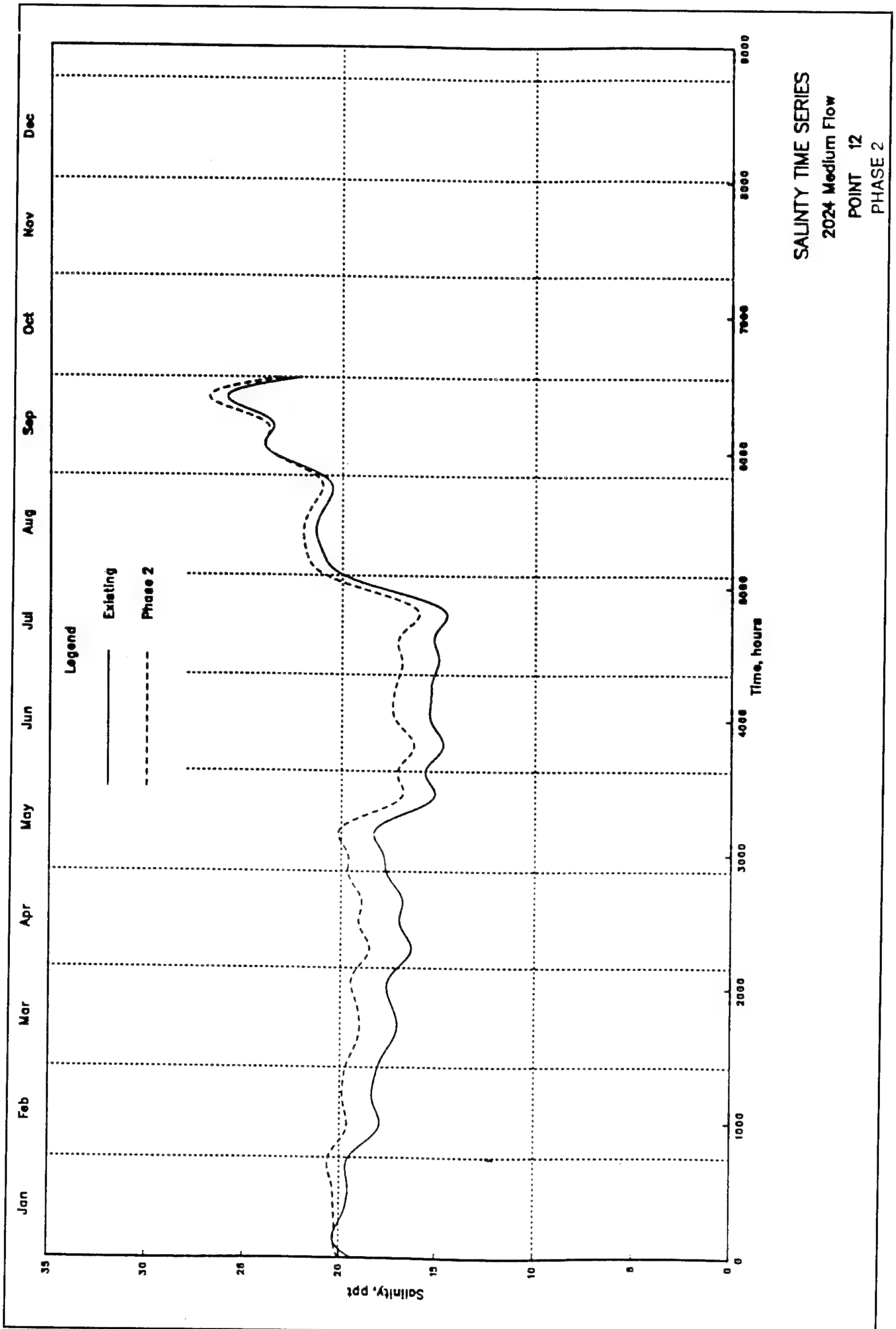


SALINTY TIME SERIES
2024 Medium Flow
POINT 11
PHASE 2



SALINITY TIME SERIES
2024 Medium Flow
POINT 12
PHASE 2
Legend
Existing
Phase 2
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Salinity, ppt
Time, hours
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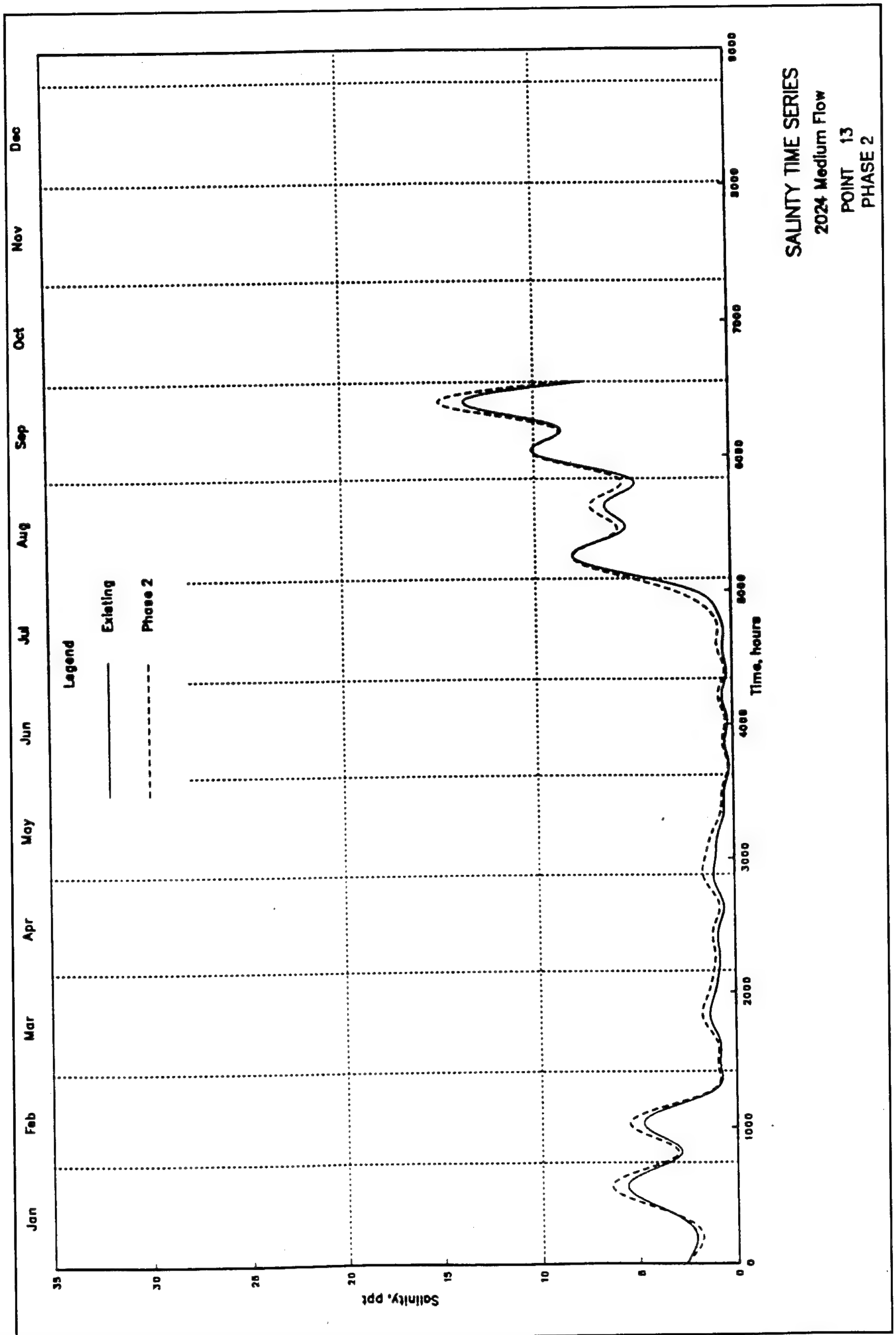
SALINITY TIME SERIES
2024 Medium Flow
POINT 13
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
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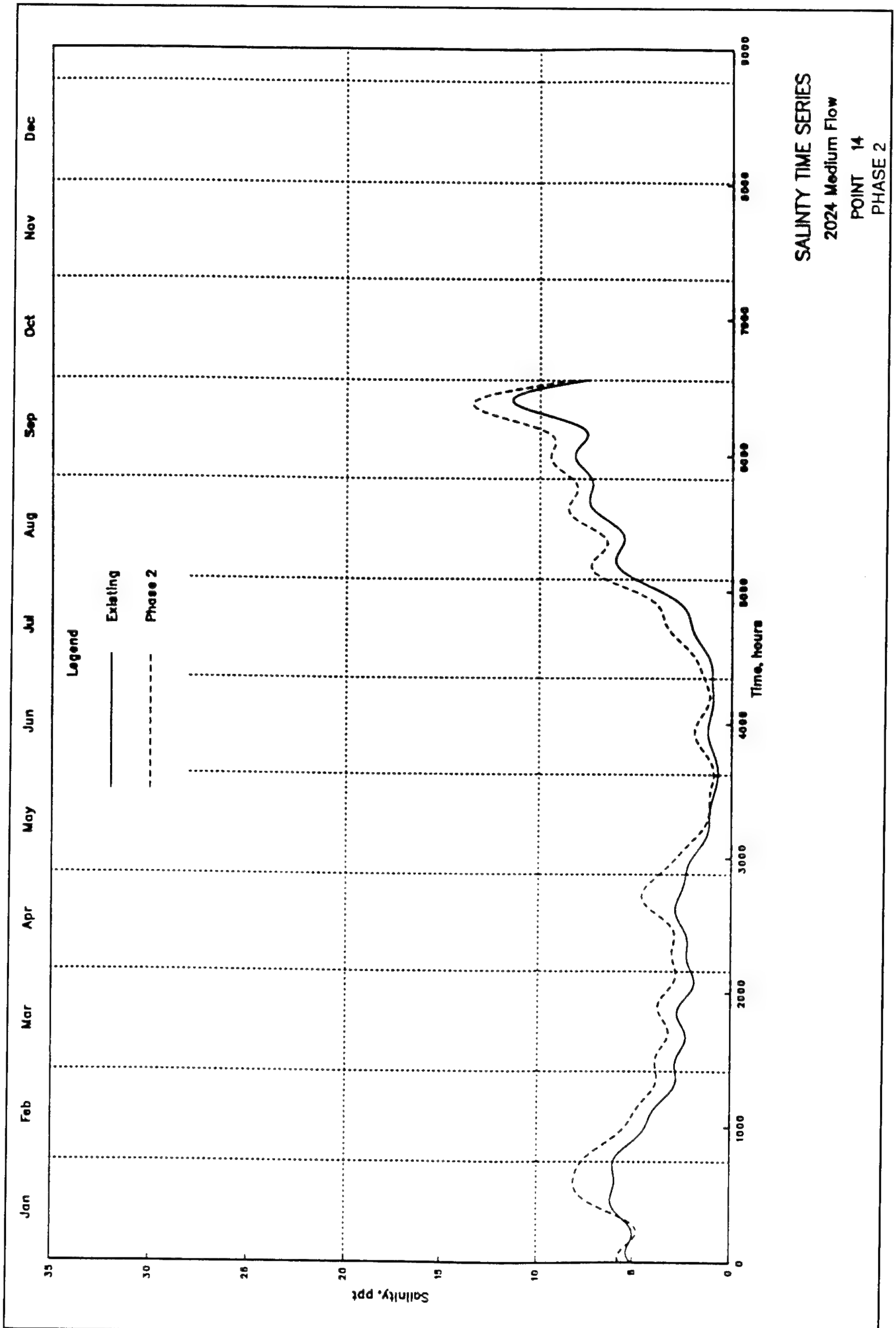
Plate 205


SALINTY TIME SERIES
2024 Medium Flow
POINT 14
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
Jan
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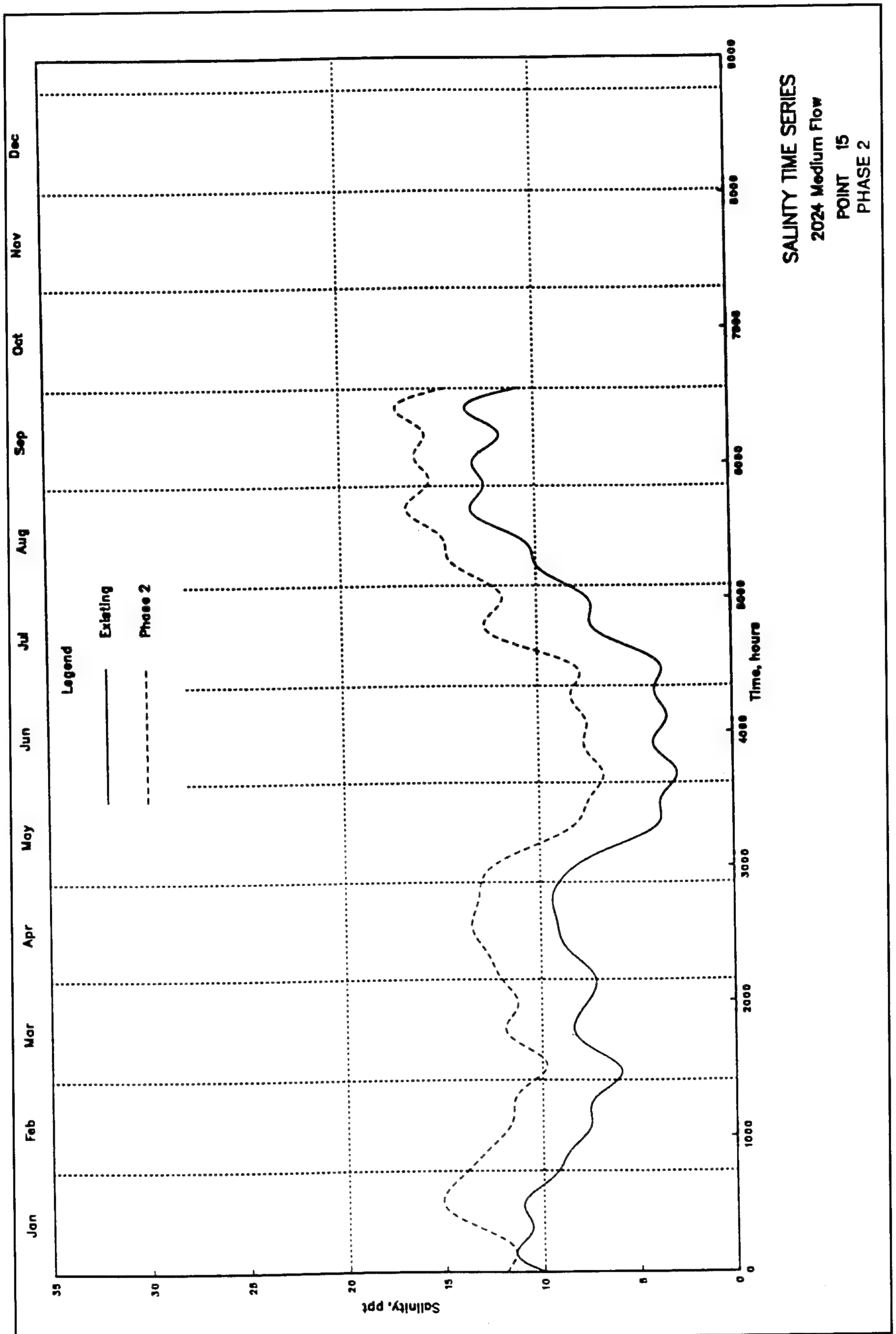
SALINITY TIME SERIES
2024 Medium Flow
POINT 15
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
Jan
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Plate 207

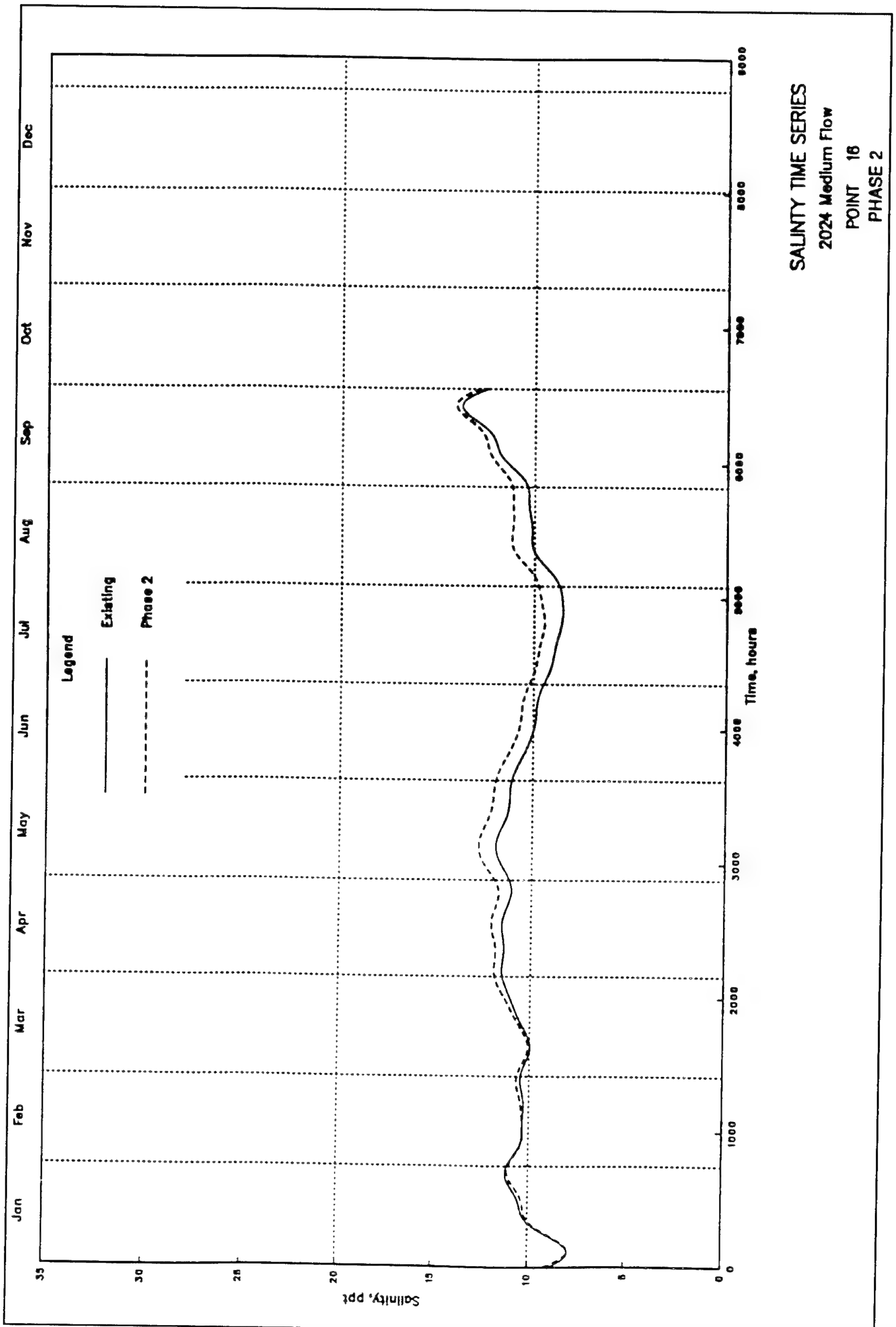
SALINTY TIME SERIES
2024 Medium Flow
POINT 16
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
Jan
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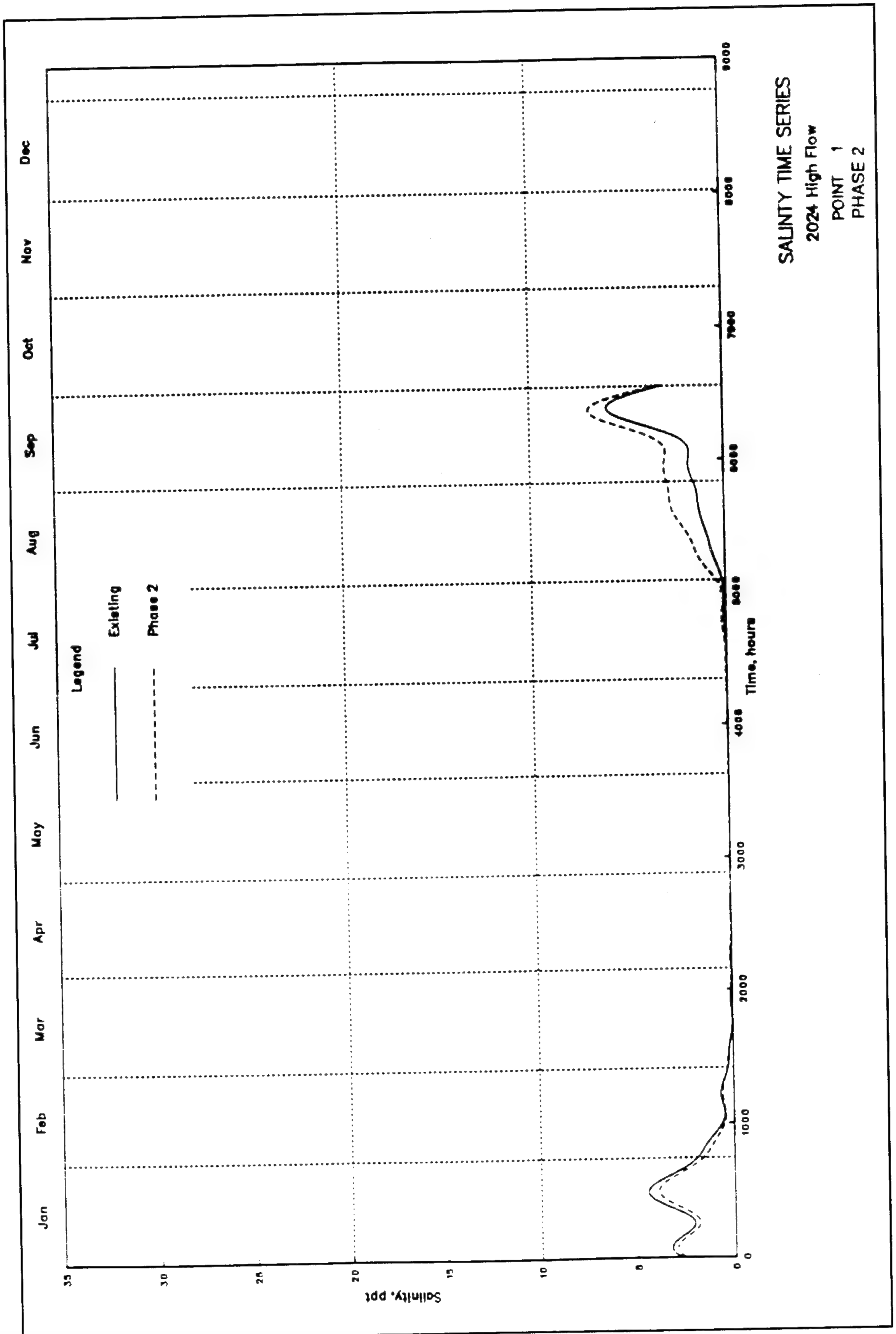
Plate 208


SALINTY TIME SERIES
2024 High Flow
POINT 1
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
Jan
Feb
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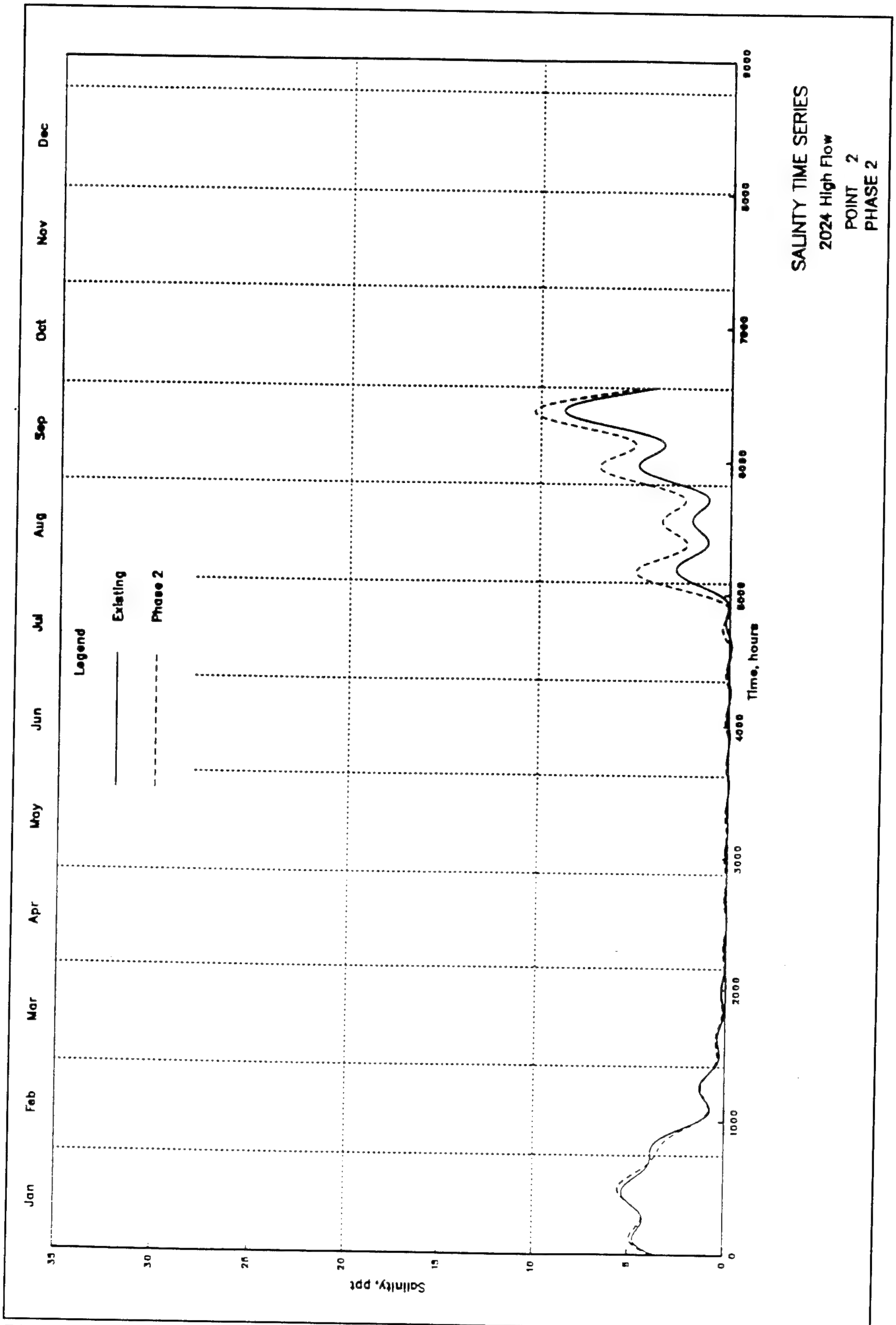

SALINTY TIME SERIES
2024 High Flow
POINT 2
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
Jan
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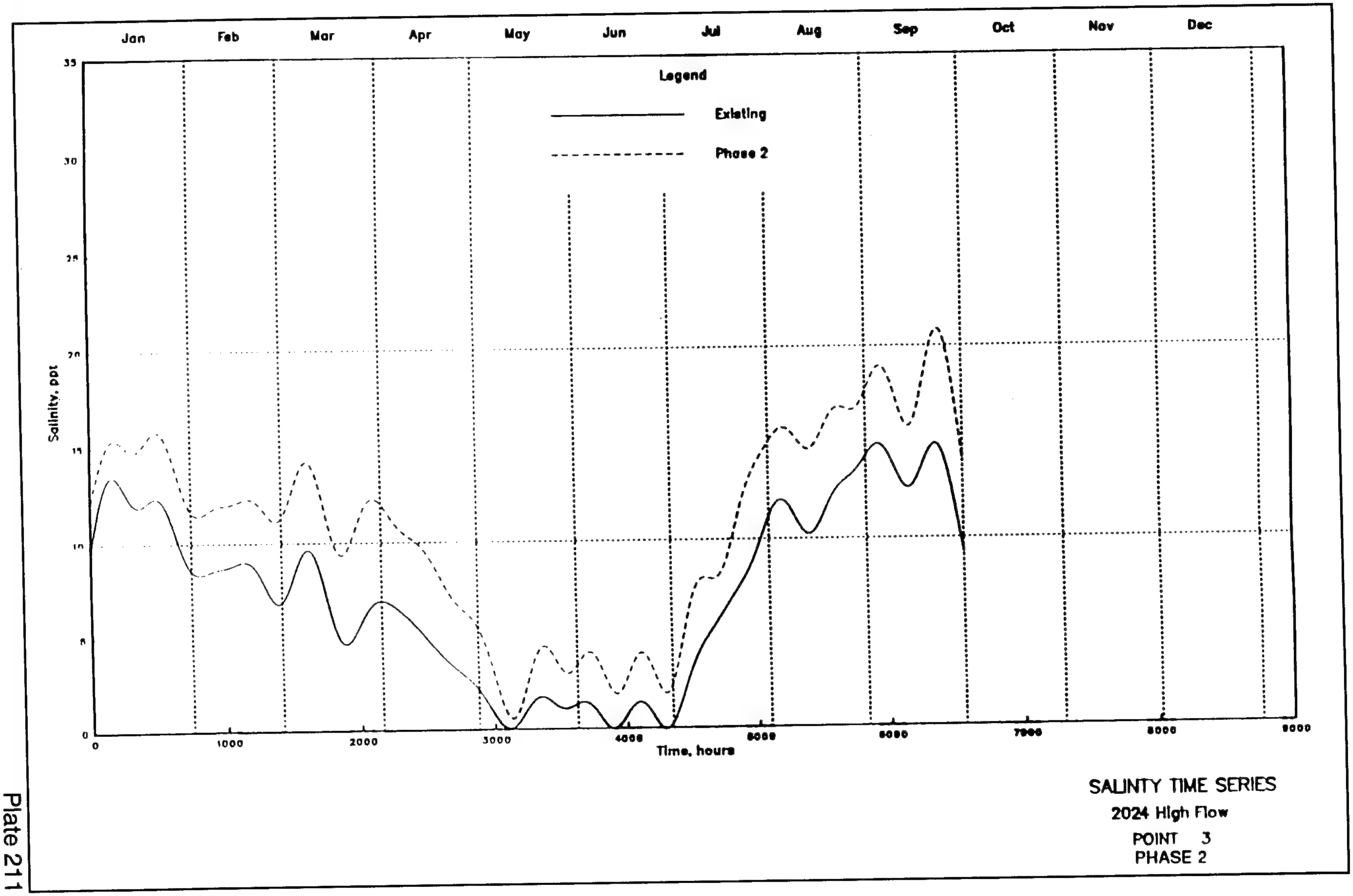
Plate 210


Jan
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Legend
Existing
Phase 2
Salinity, ppt
Time, hours
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SALINTY TIME SERIES
2024 High Flow
POINT 3
PHASE 2

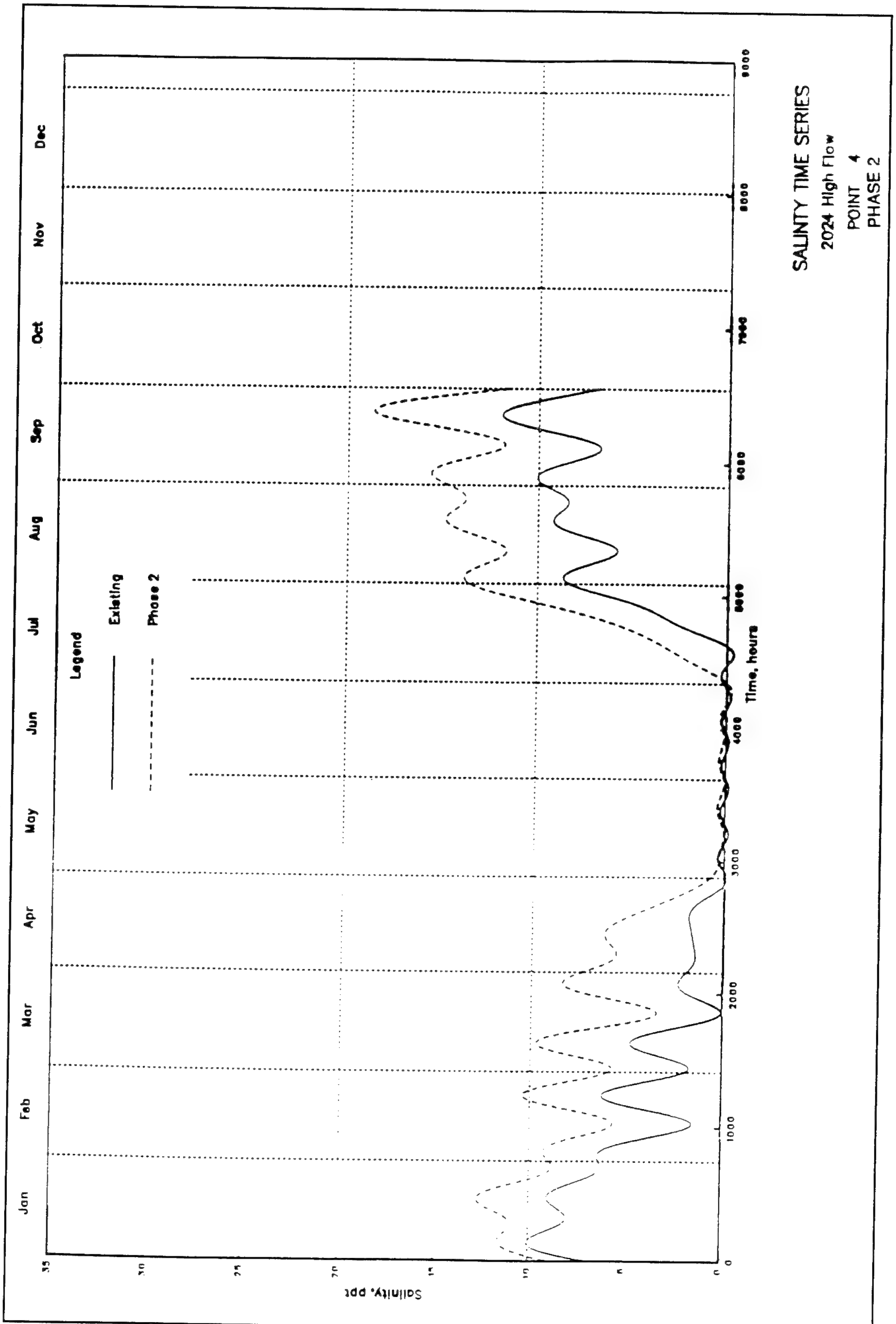
SALINITY TIME SERIES
2024 High Flow
POINT 4
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
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Plate 212

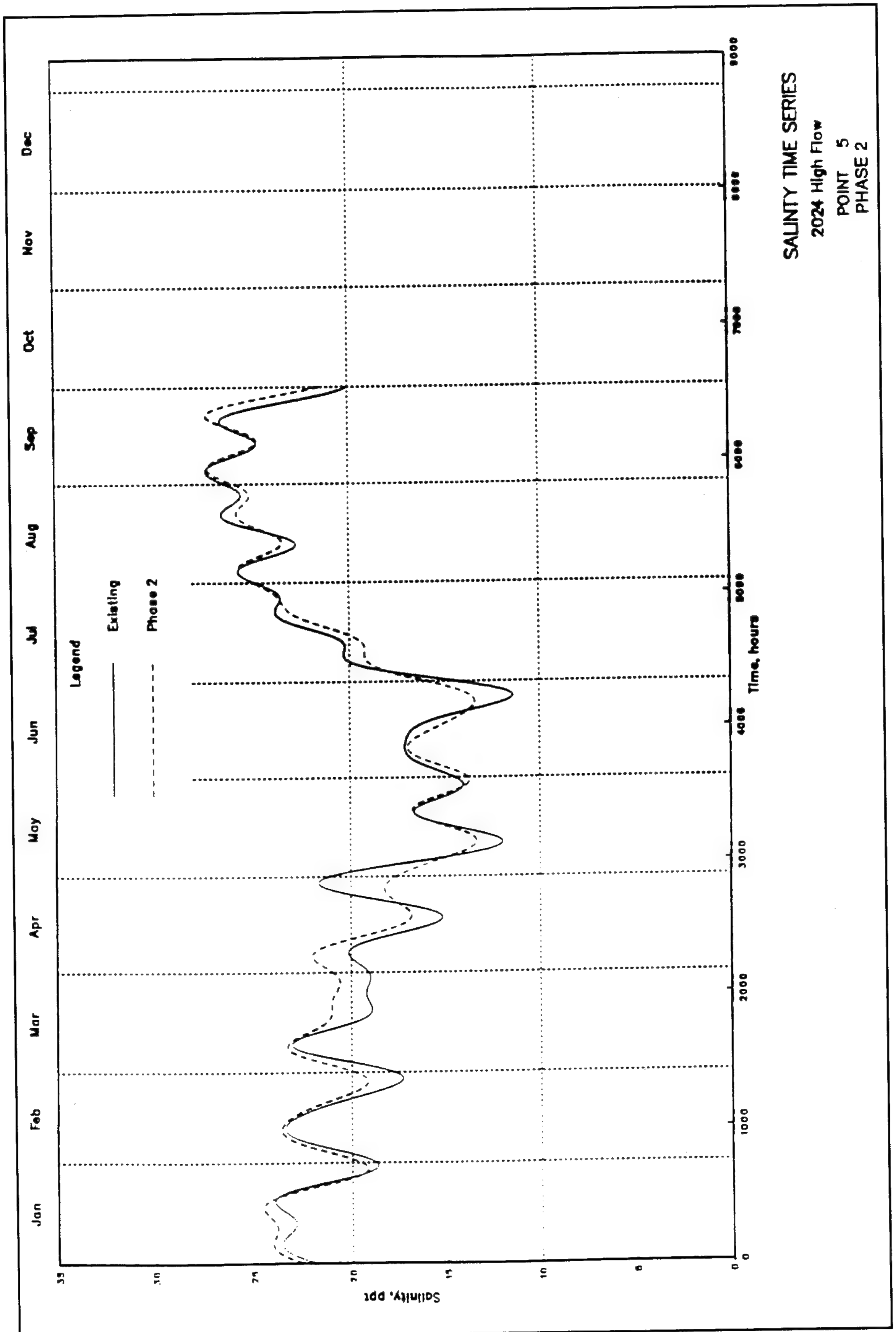
SALINTY TIME SERIES
2024 High Flow
POINT 5
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
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Plate 213

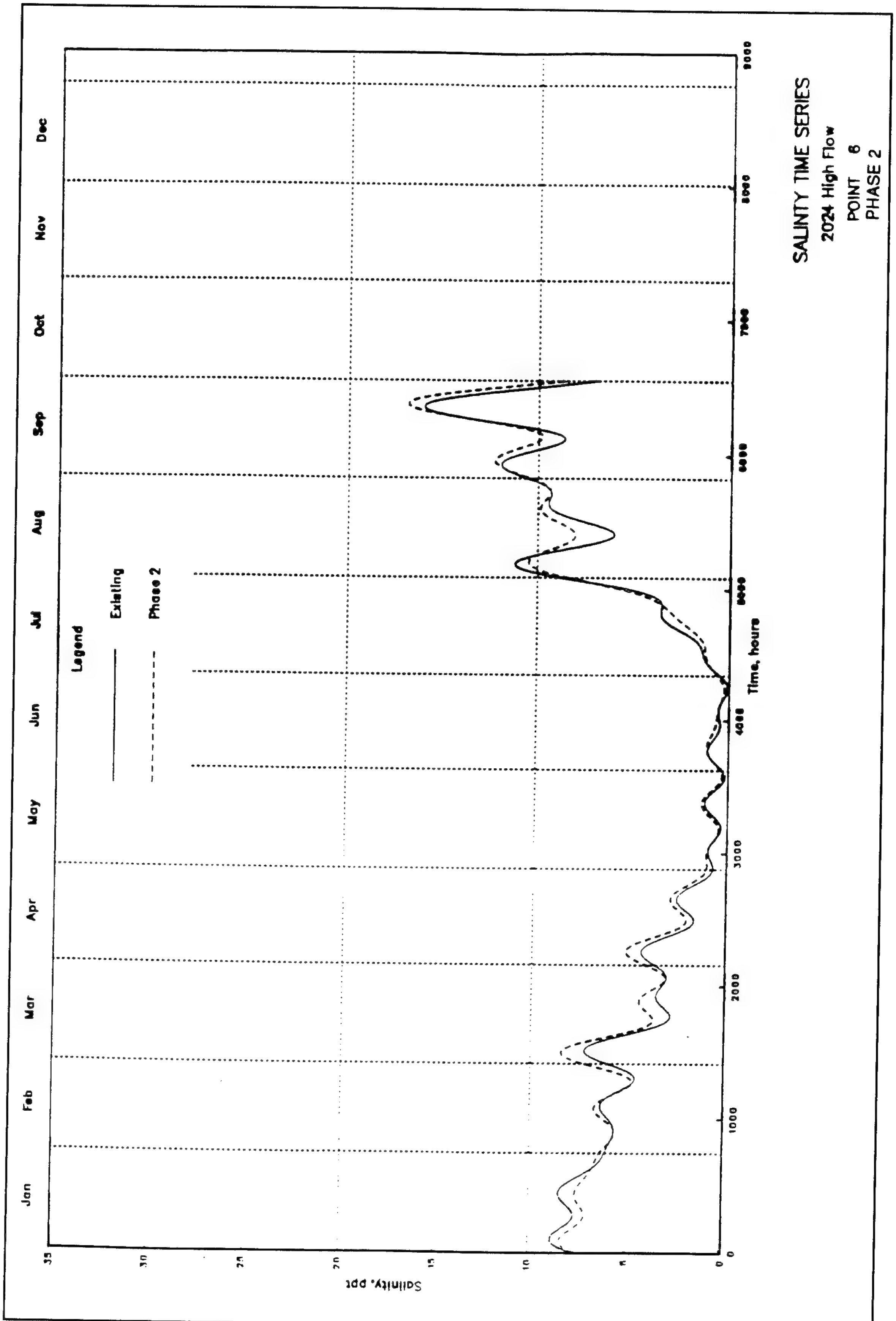
SALINTY TIME SERIES
2024 High Flow
POINT 6
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
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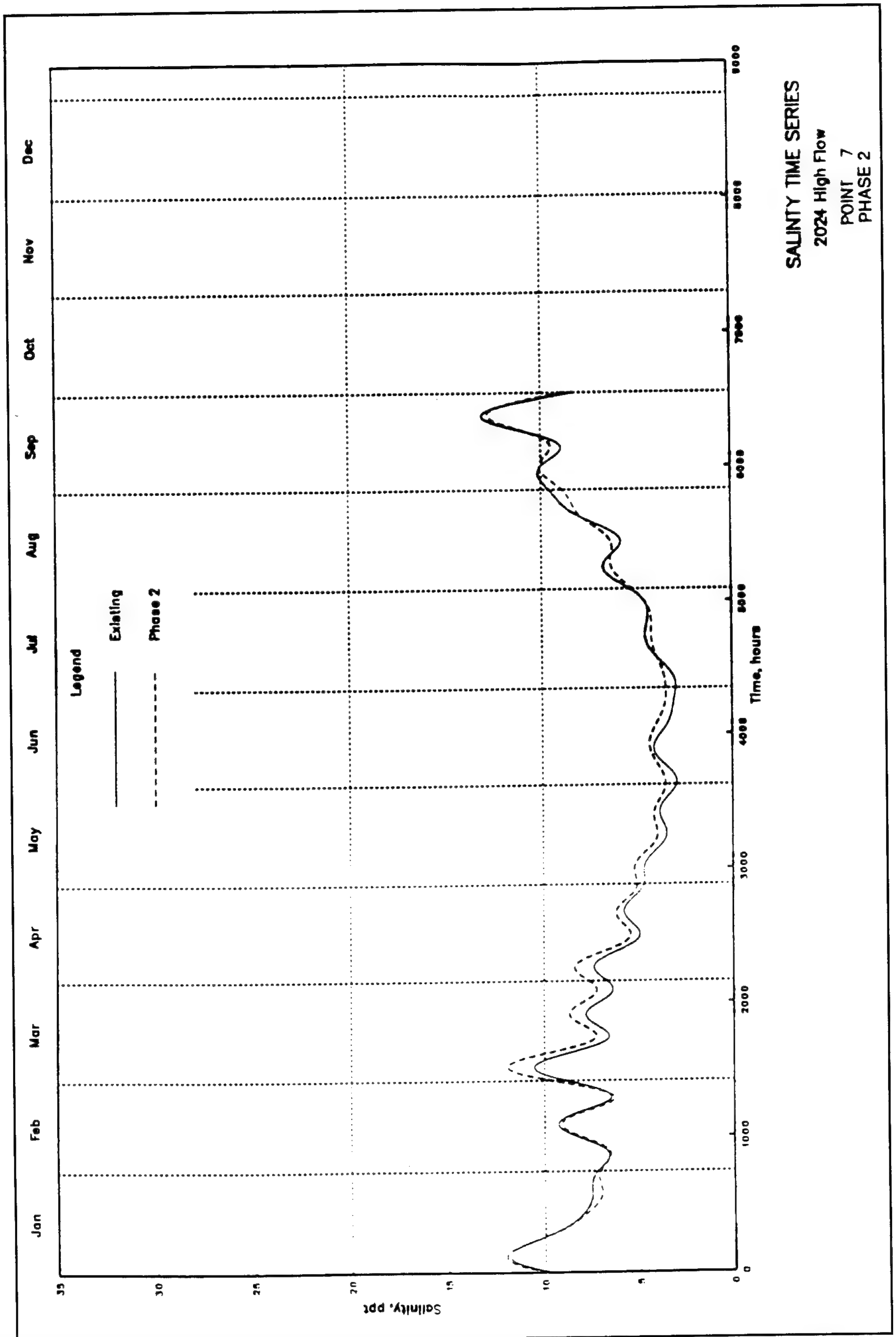
Plate 214



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Legend
Existing
Phase 2
Salinity, ppt
Time, hours
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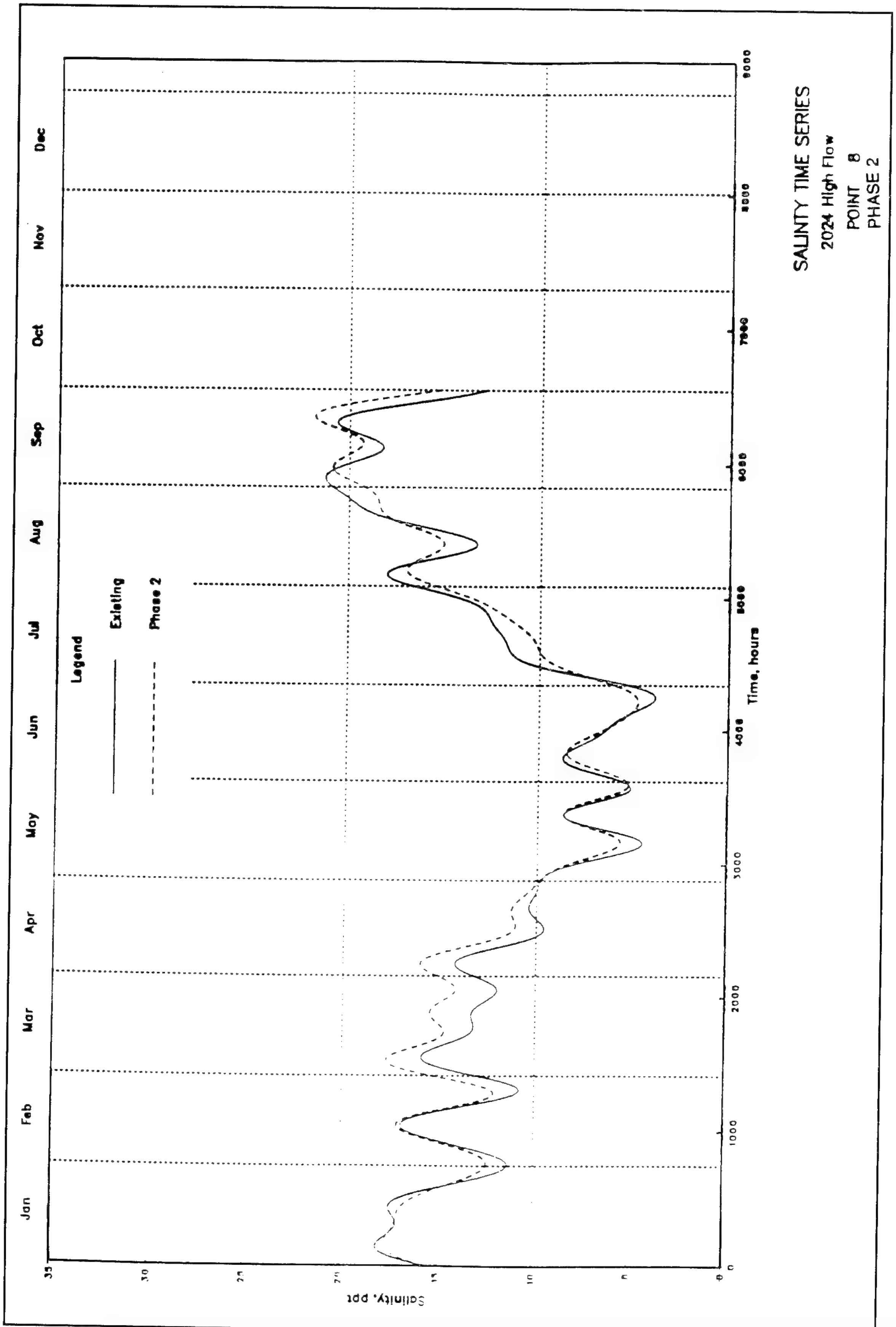
SALINTY TIME SERIES
2024 High Flow
POINT 7
PHASE 2

Plate 215


SALINITY TIME SERIES
2024 High Flow
POINT 8
PHASE 2
Legend
Existing
Phase 2
Jan
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Time, hours
Salinity, ppt
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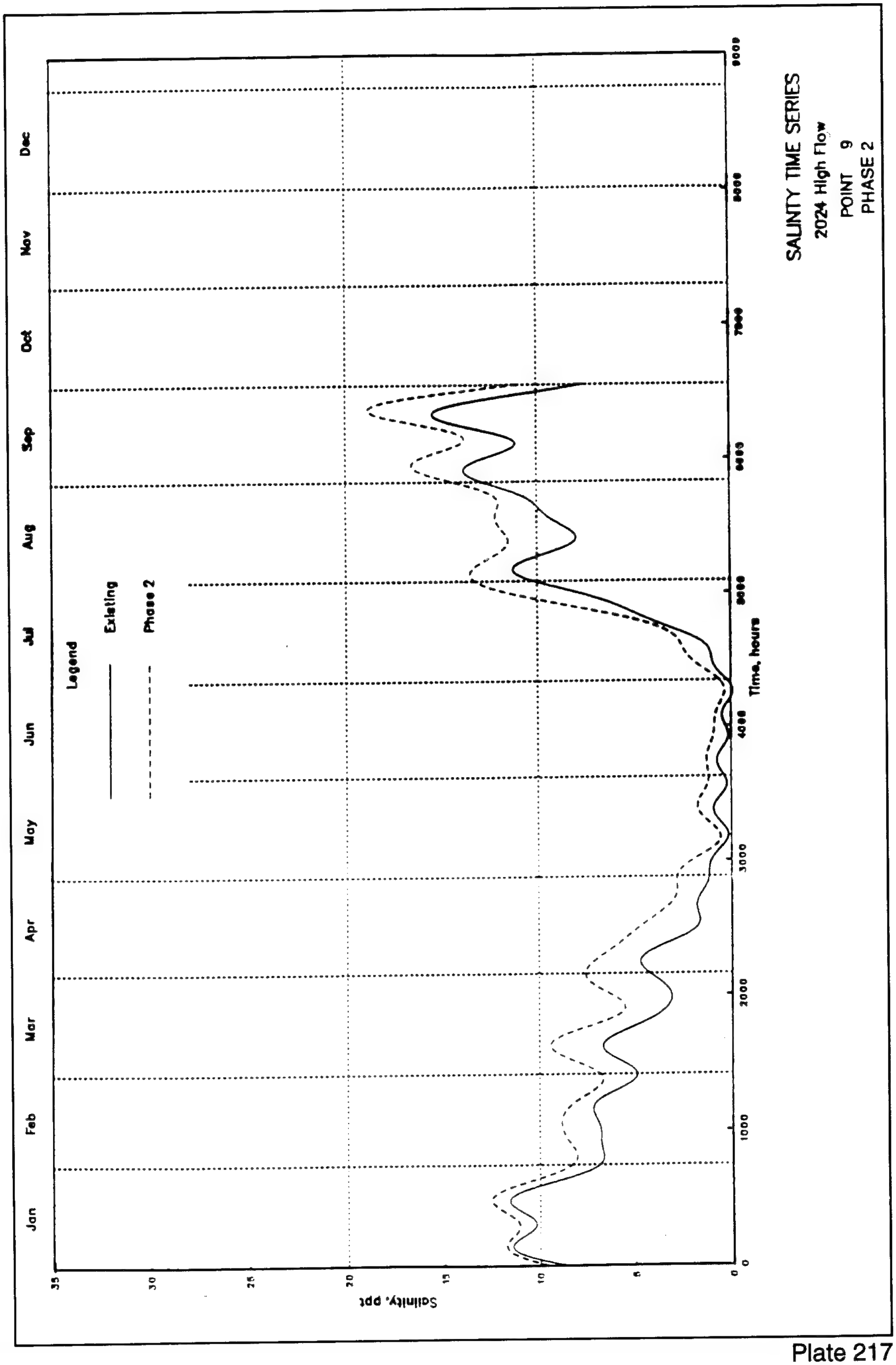
Plate 216


SALINITY TIME SERIES
2024 High Flow
POINT 9
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
Jan
Feb
Mar
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May
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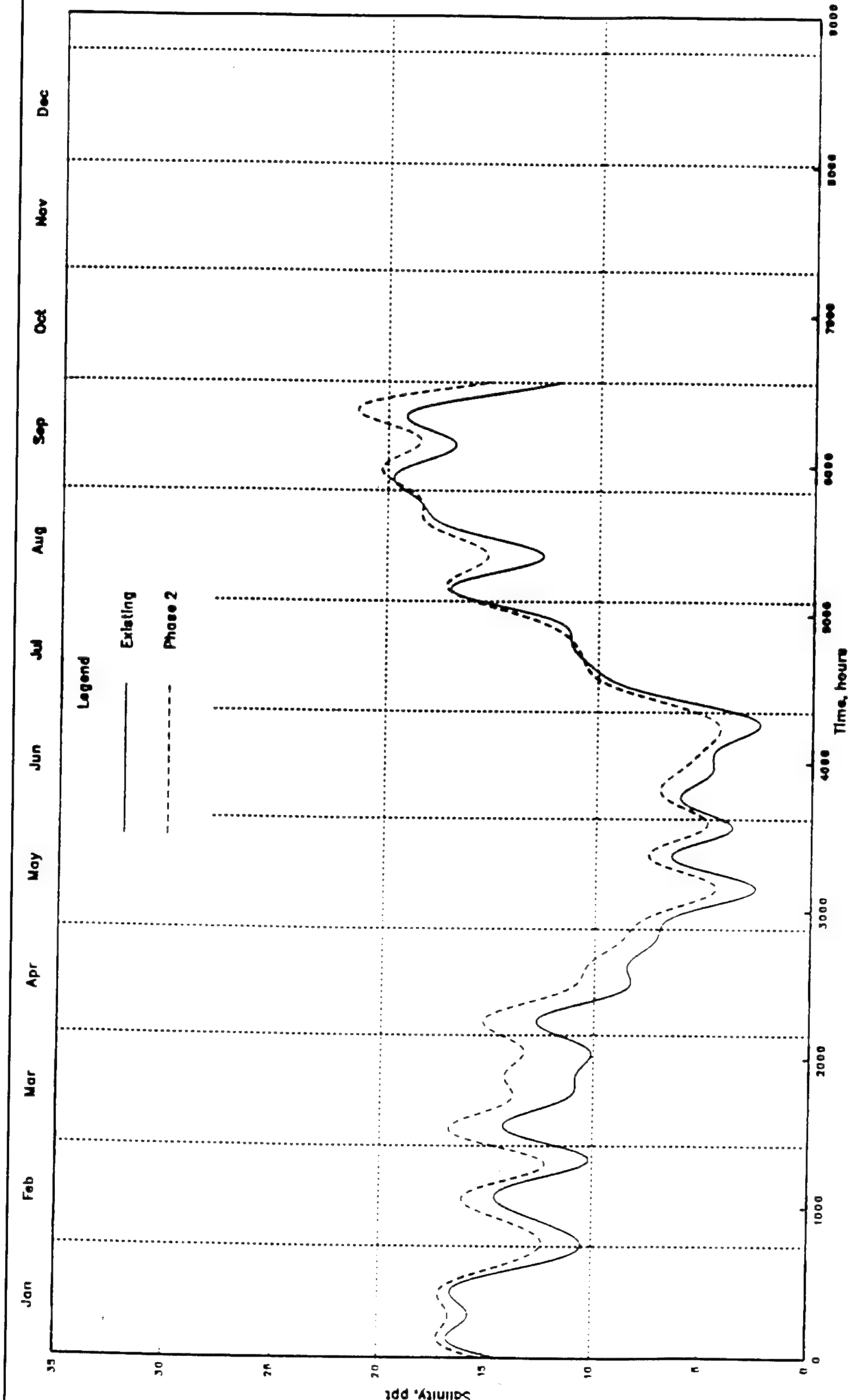

SALINTY TIME SERIES
2024 High Flow
POINT 10
PHASE 2

Plate 218

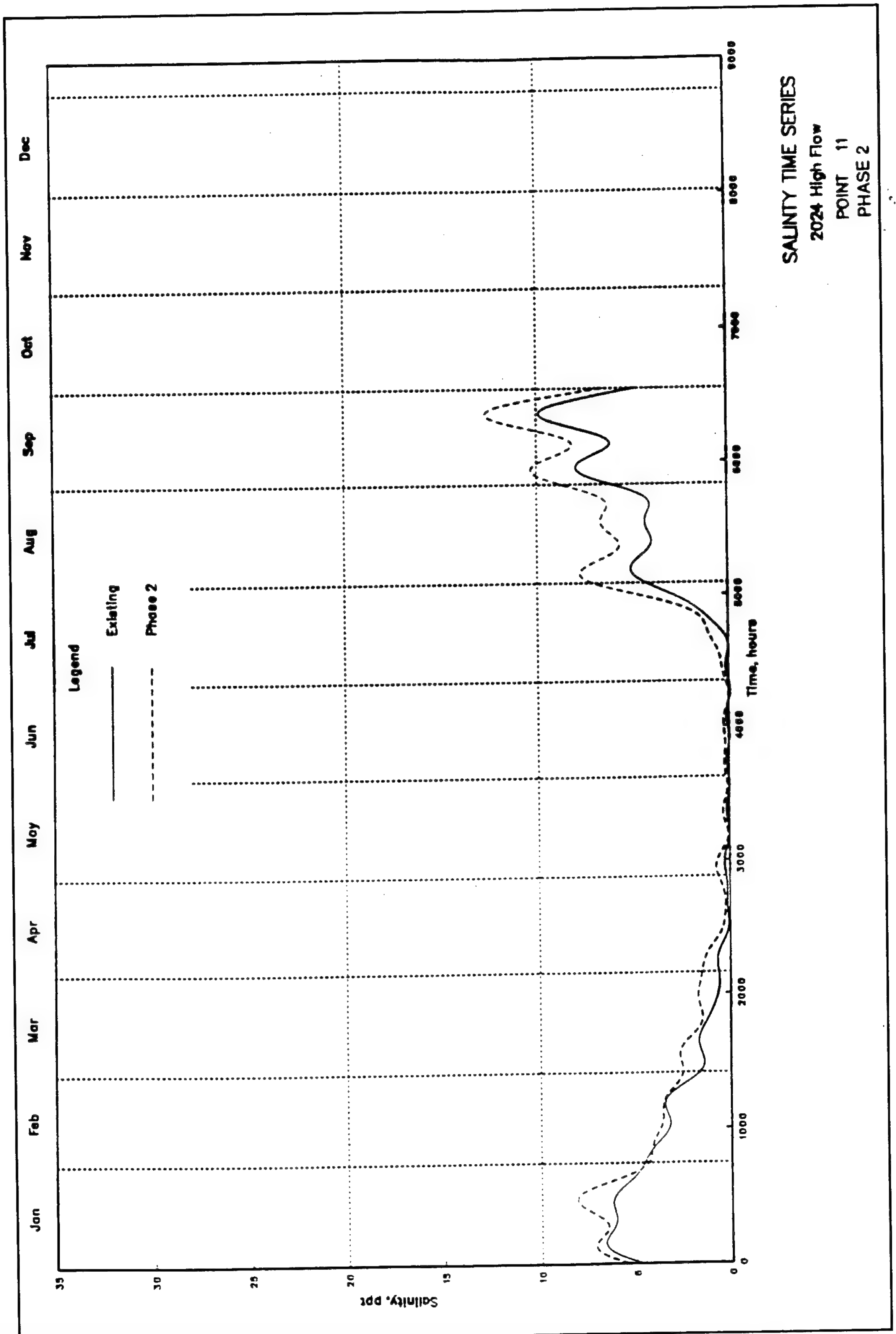
SALINTY TIME SERIES
2024 High Flow
POINT 11
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
Jan
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Plate 219

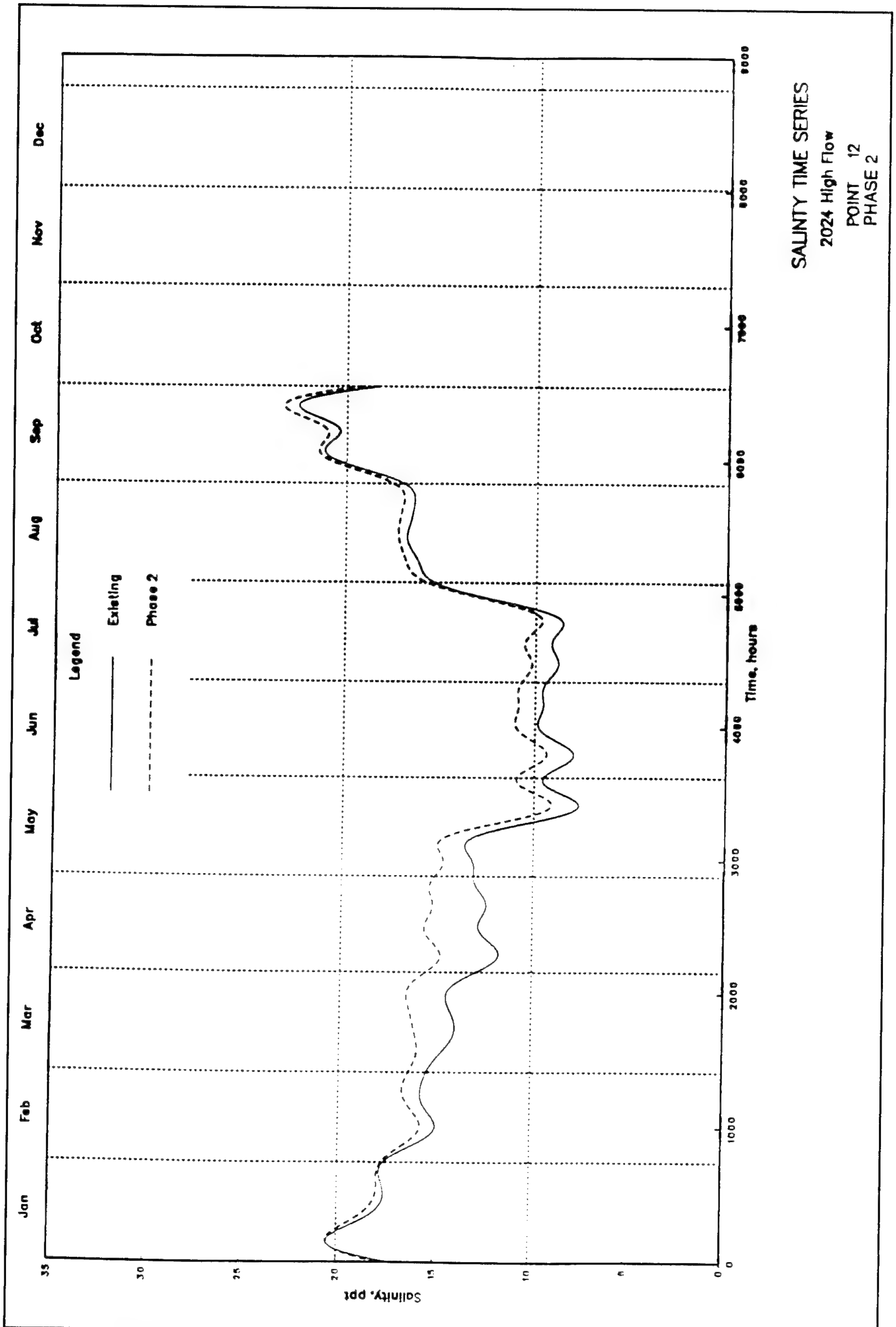
SALINITY TIME SERIES
2024 High Flow
POINT 12
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
Jan
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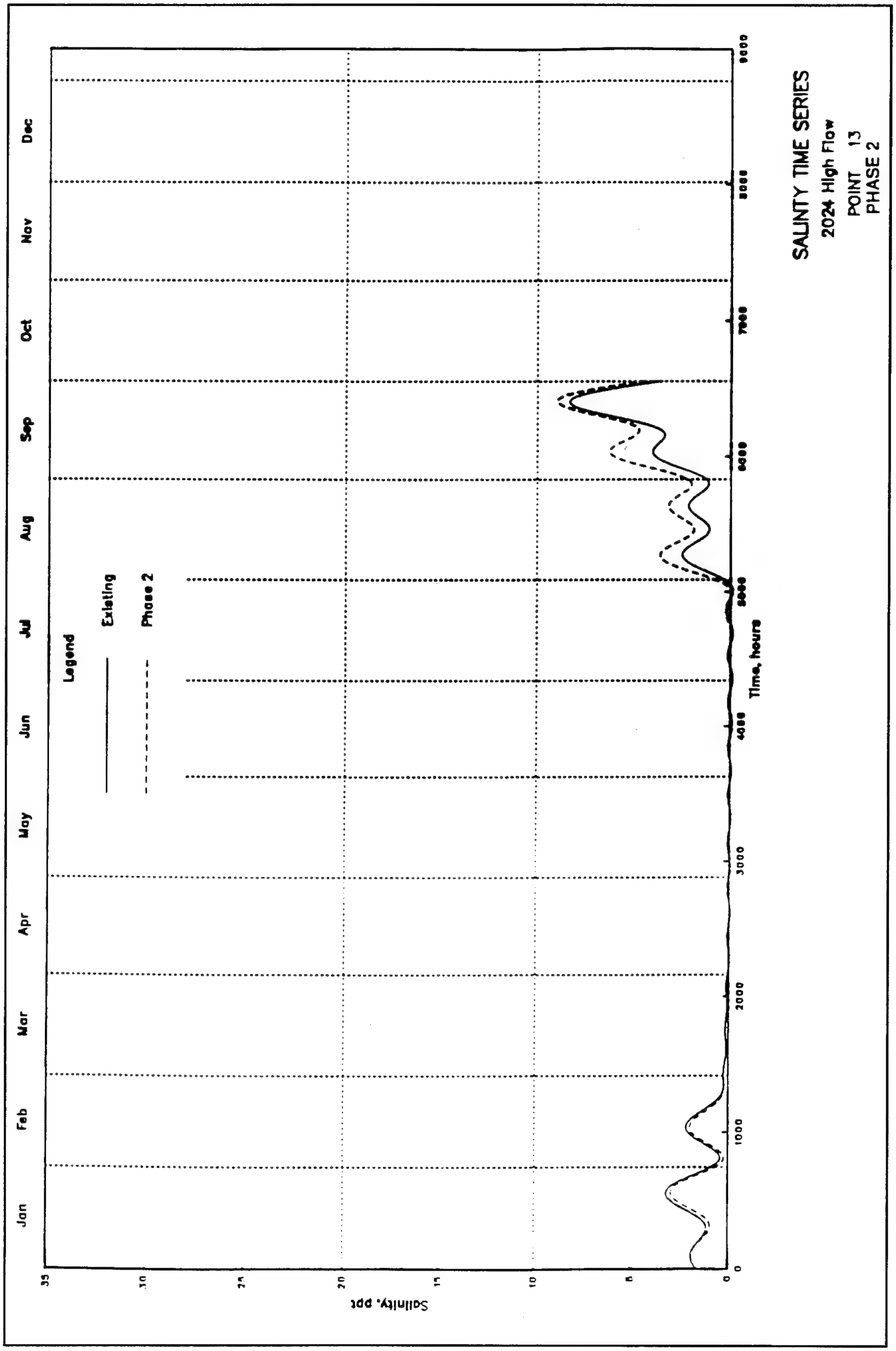
Plate 220



SALINTY TIME SERIES
2024 High Flow
POINT 13
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
Jan
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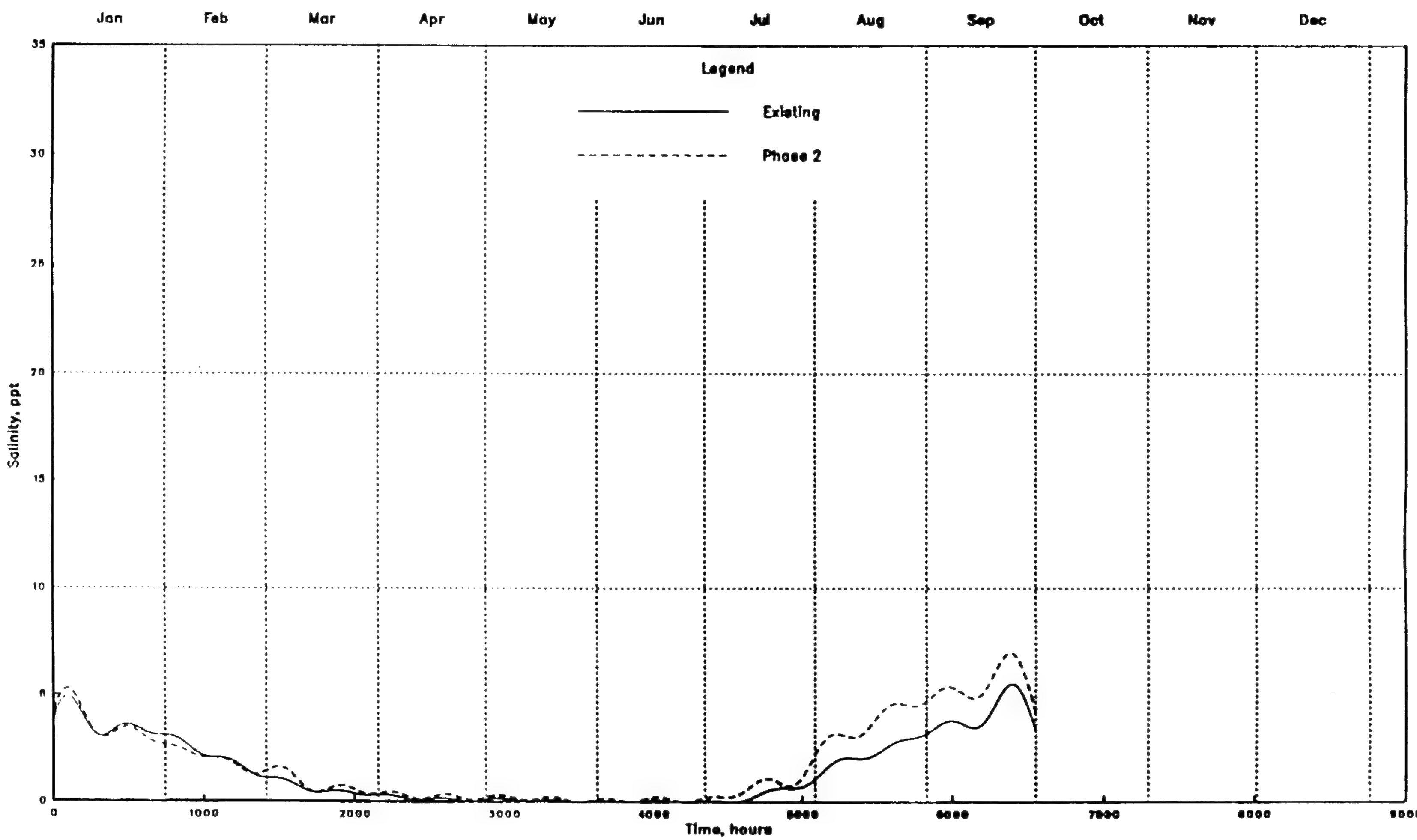
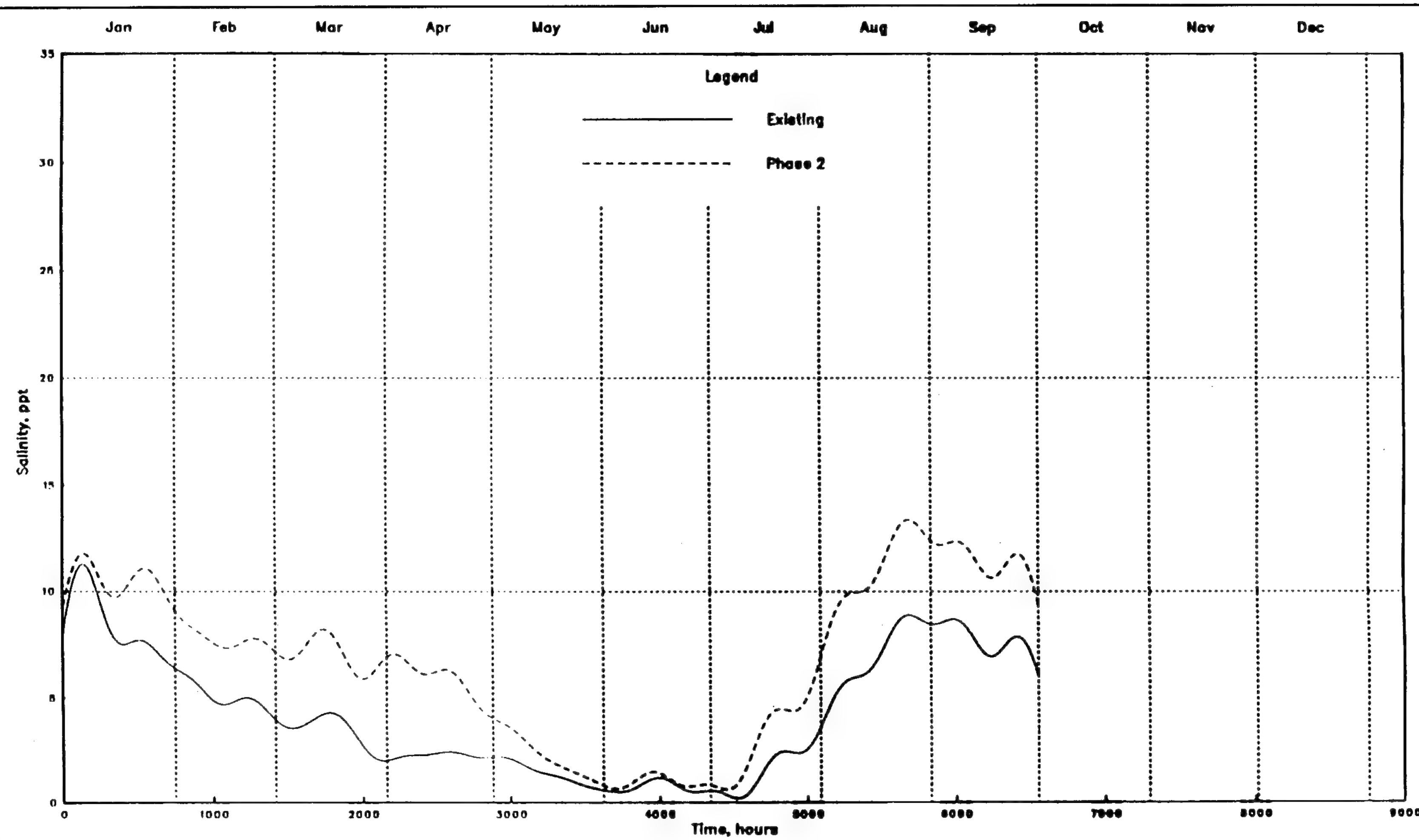
Plate 221

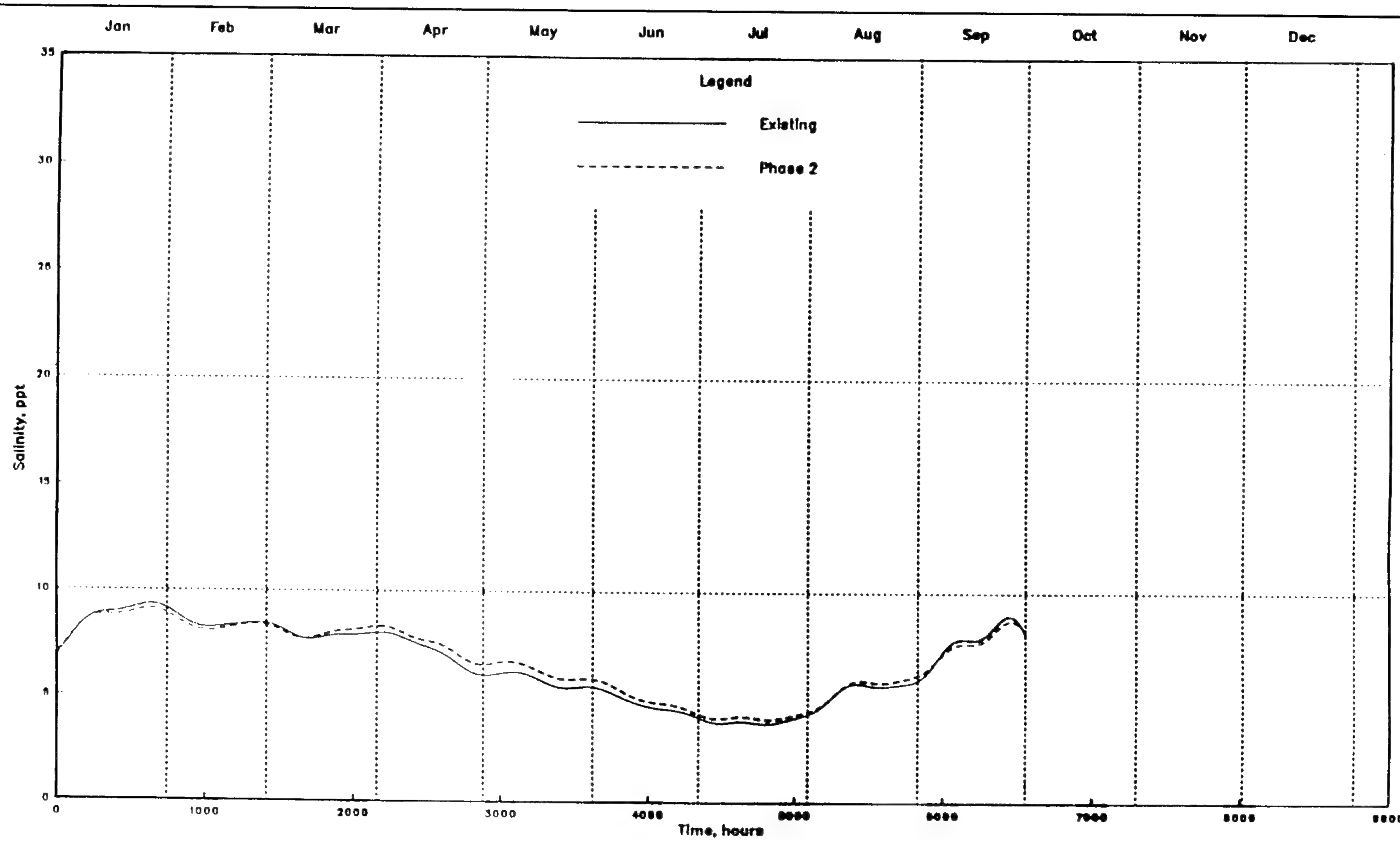
Plate 222



SALINTY TIME SERIES
2024 High Flow
POINT 14
PHASE 2

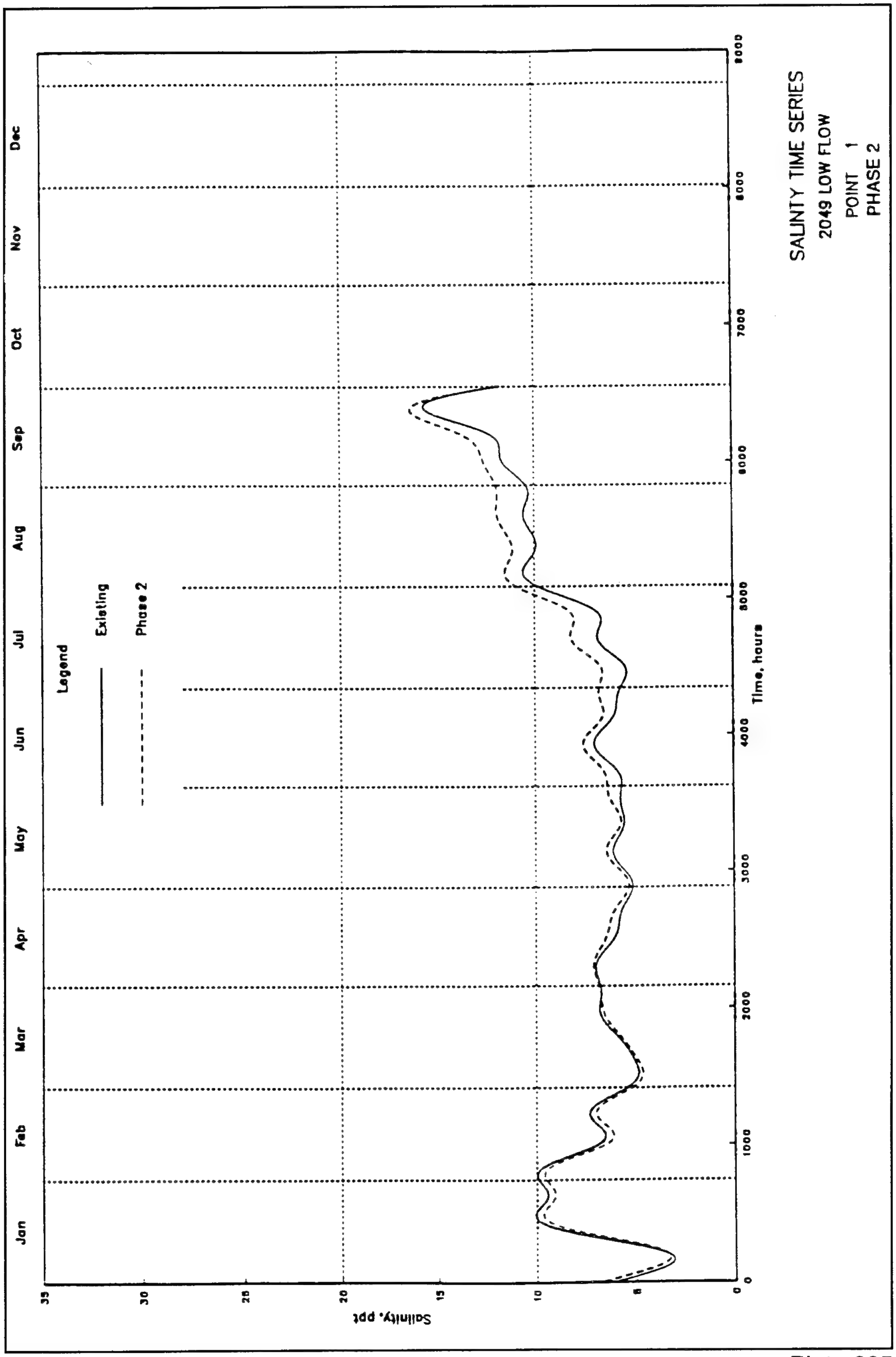


SALINTY TIME SERIES
2024 High Flow
POINT 15
PHASE 2



SALINTY TIME SERIES
2024 High Flow
POINT 16
PHASE 2

Plate 224



SALINTY TIME SERIES
2049 LOW FLOW
POINT 1
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
Jan
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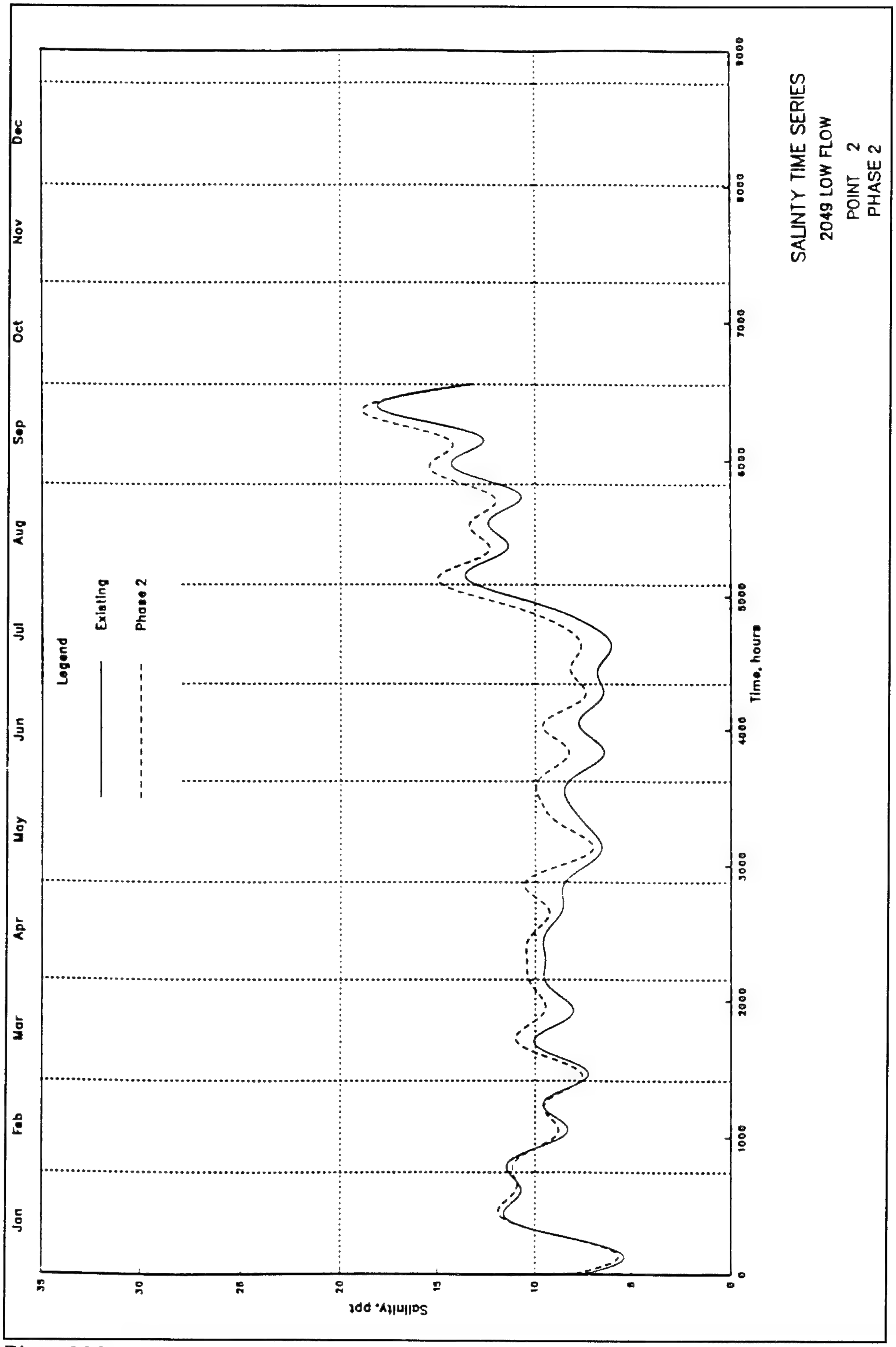
SALINTY TIME SERIES
2049 LOW FLOW
POINT 2
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
Jan
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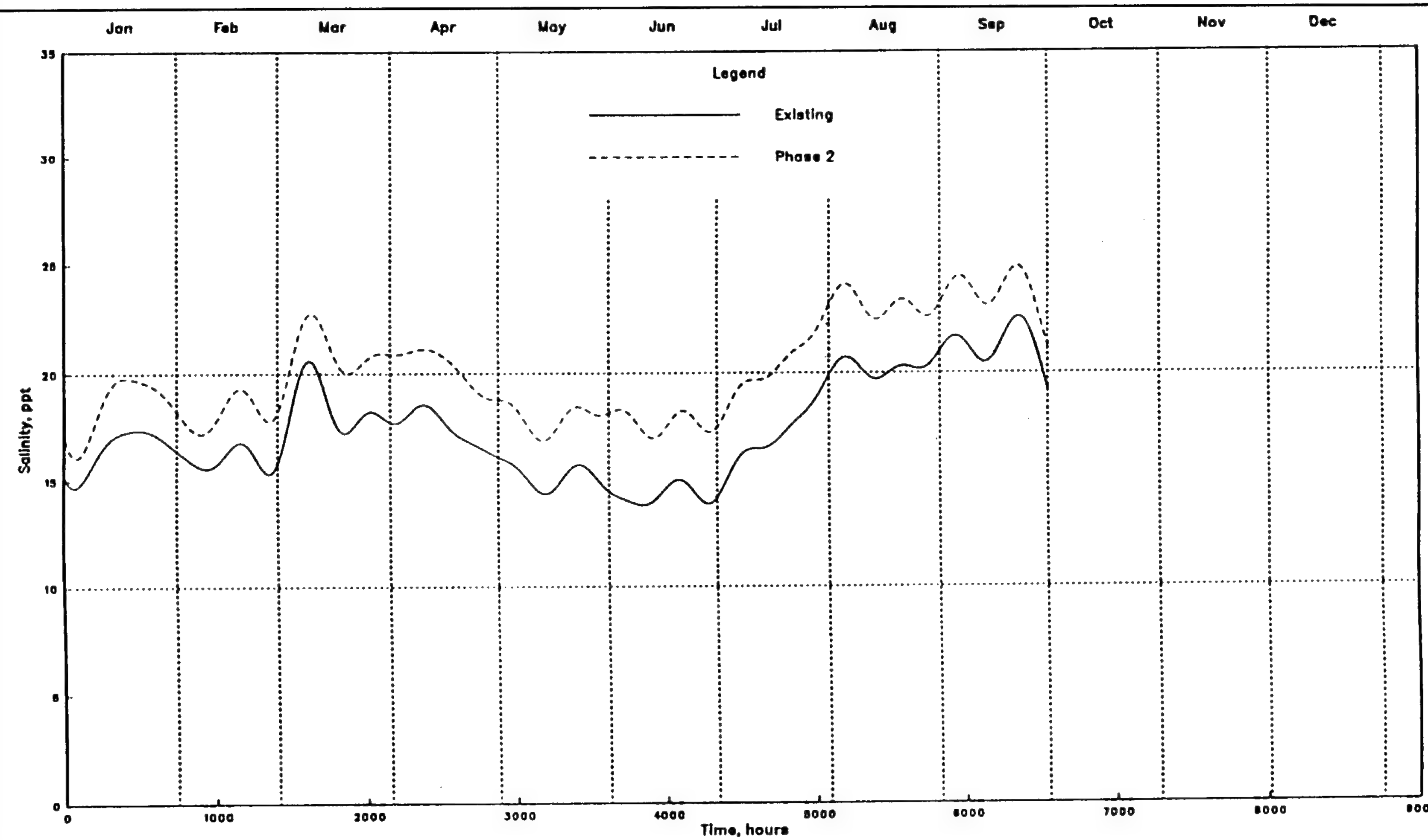
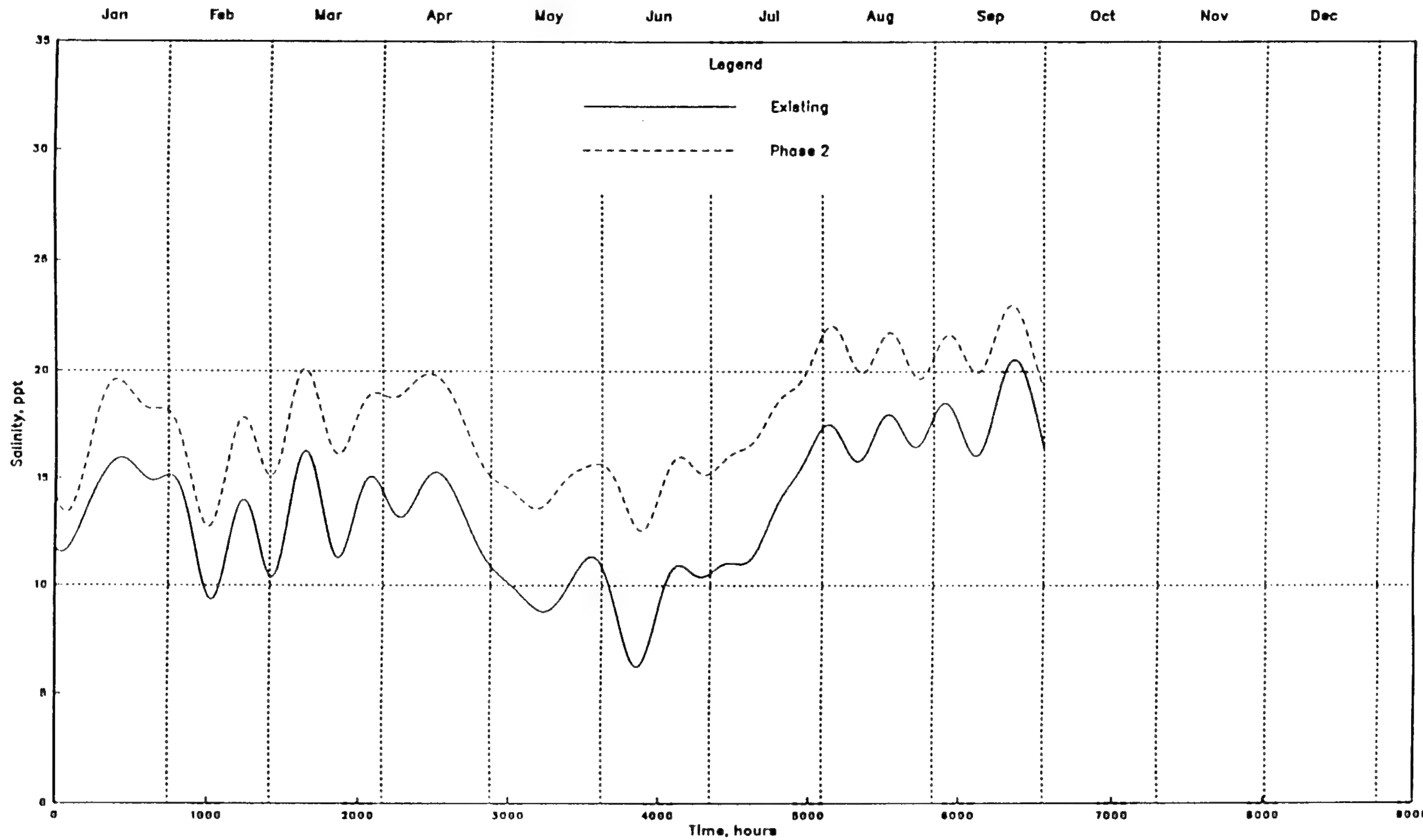
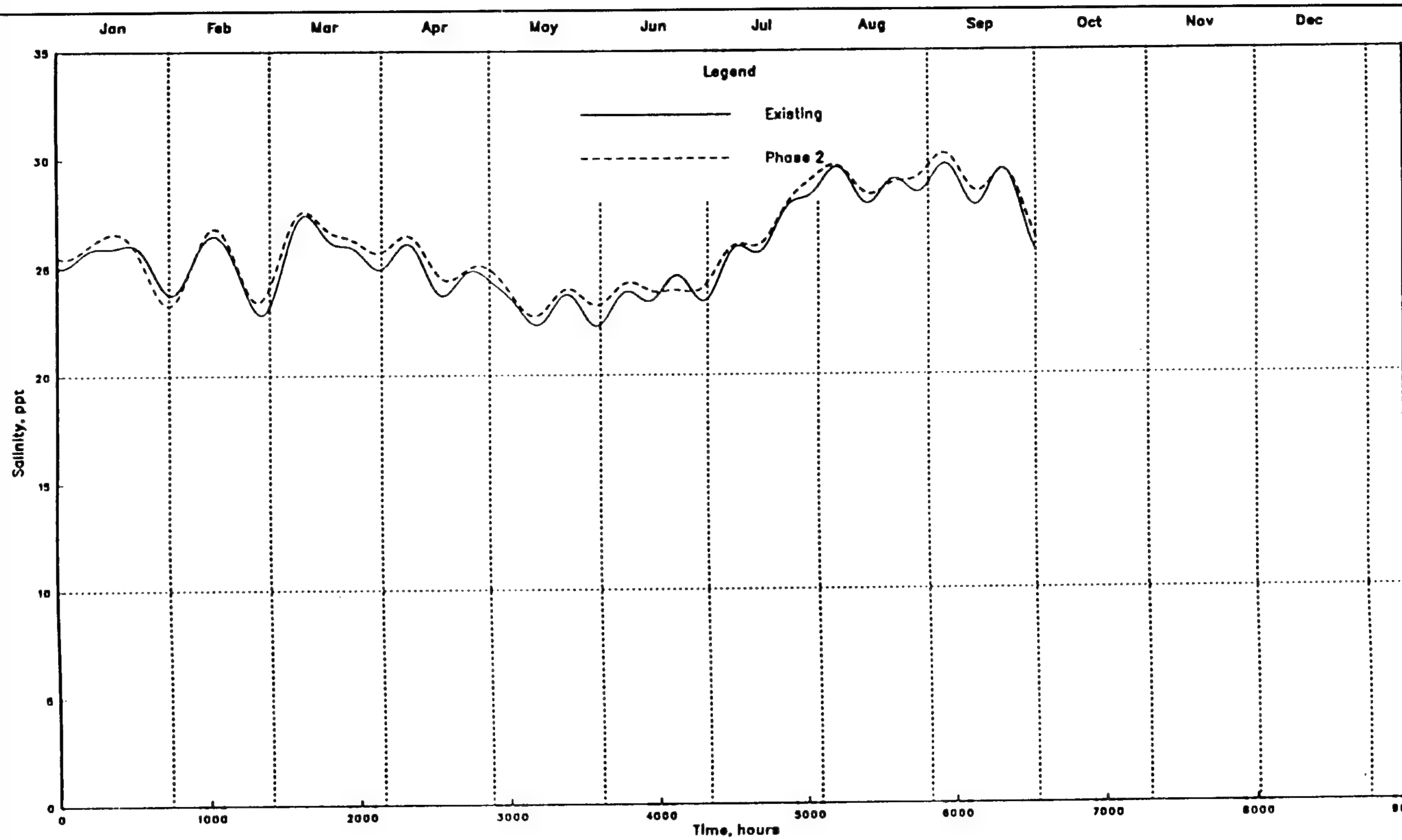
Plate 226



SALINTY TIME SERIES
2049 LOW FLOW
POINT 3
PHASE 2



SALINTY TIME SERIES
2049 LOW FLOW
POINT 4
PHASE 2



SALINTY TIME SERIES
2049 LOW FLOW
POINT 5
PHASE 2

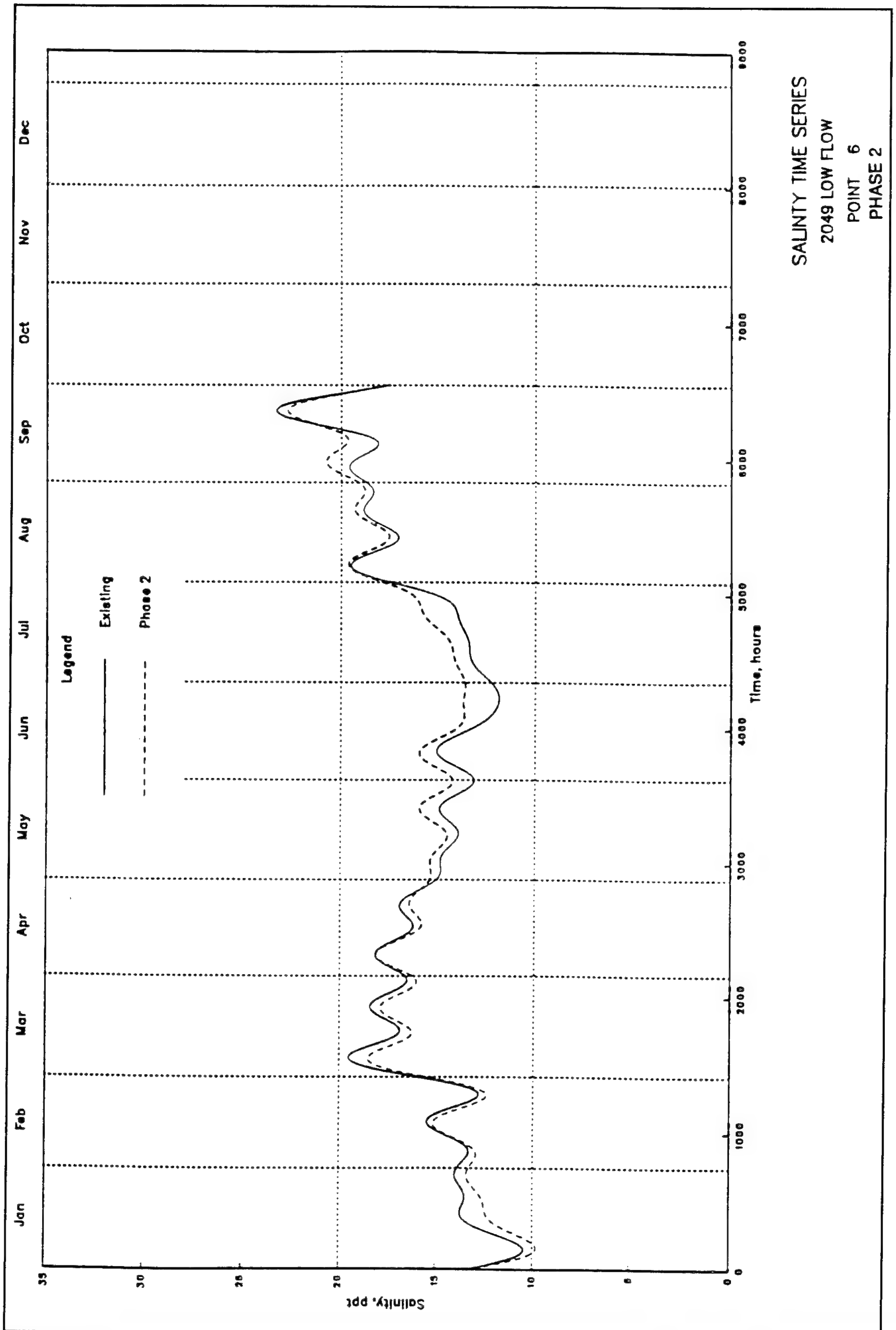

SALINTY TIME SERIES
2049 LOW FLOW
POINT 6
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
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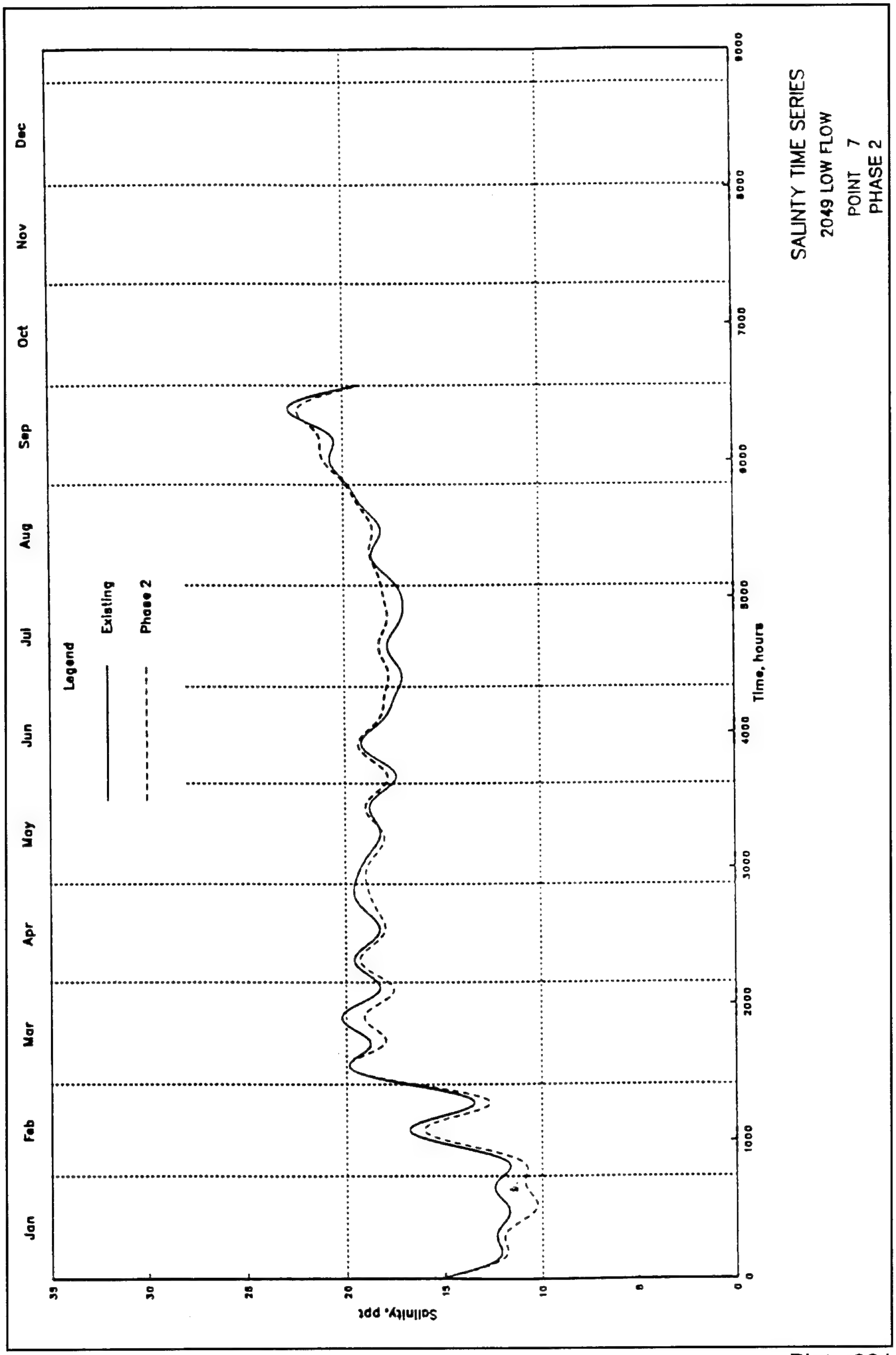
Plate 230


SALINTY TIME SERIES
2049 LOW FLOW
POINT 7
PHASE 2
Legend
Existing
Phase 2
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Time, hours
Salinity, ppt
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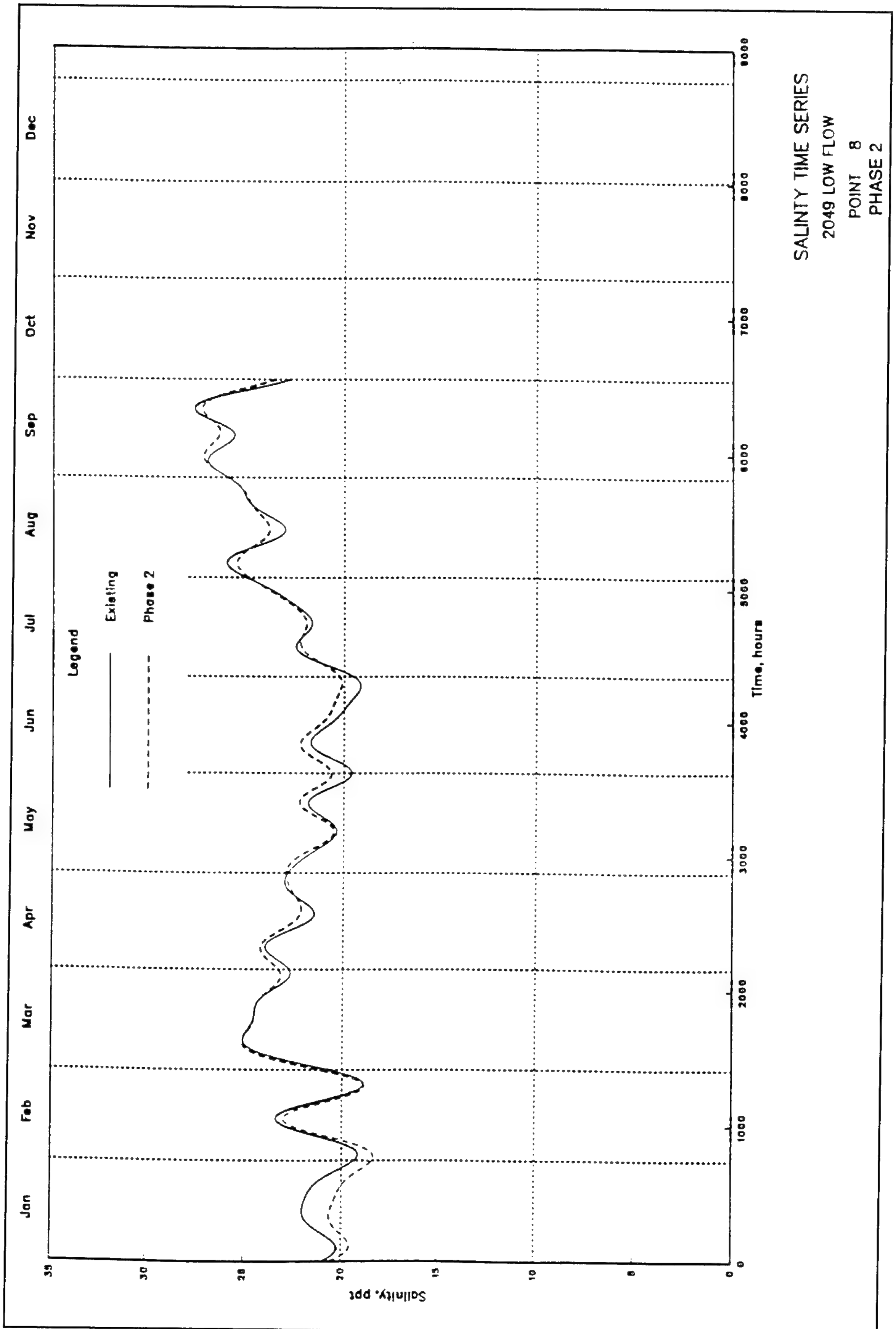
SALINTY TIME SERIES
2049 LOW FLOW
POINT 8
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
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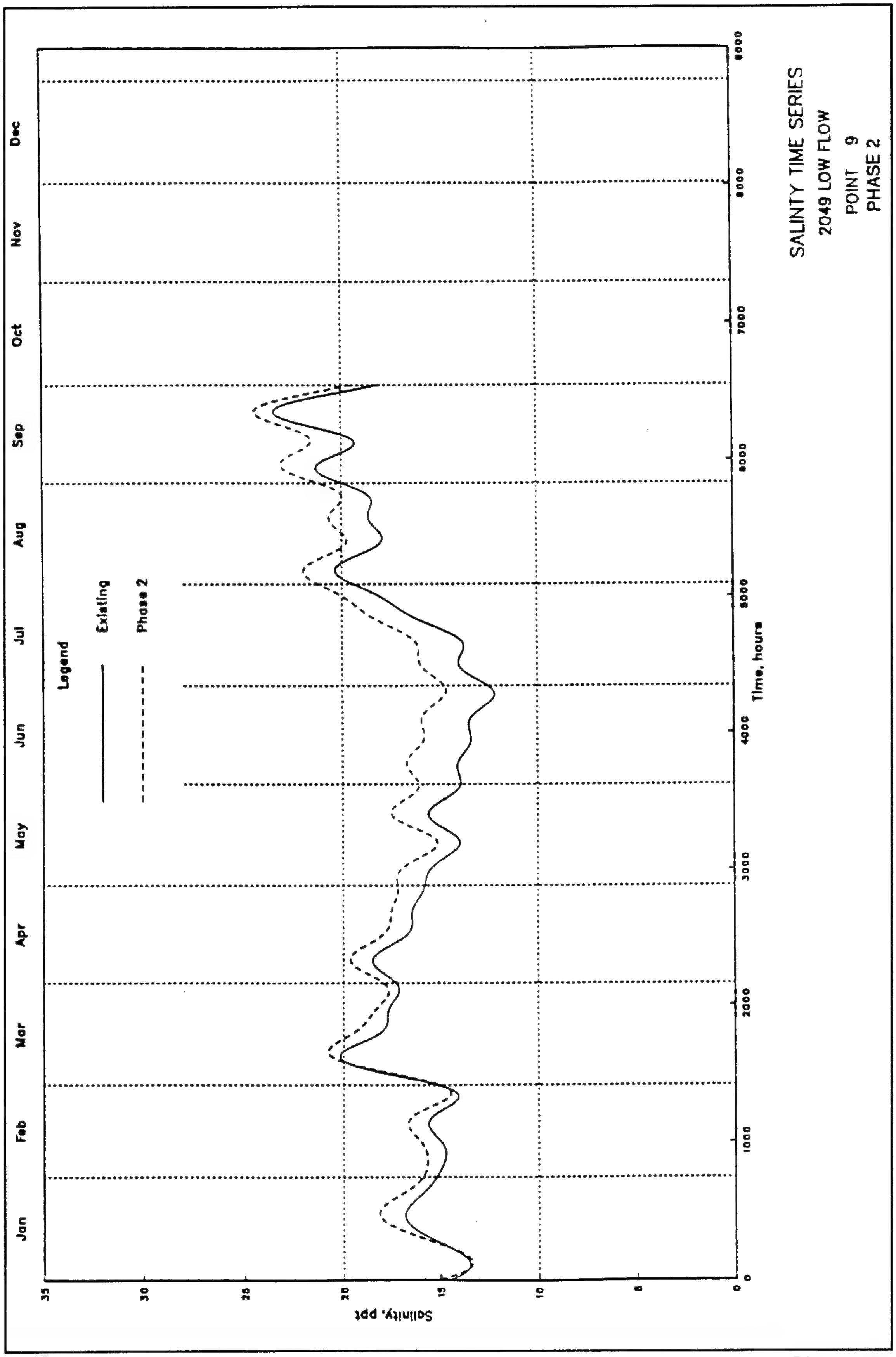
Plate 232



SALINTY TIME SERIES
2049 LOW FLOW
POINT 9
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
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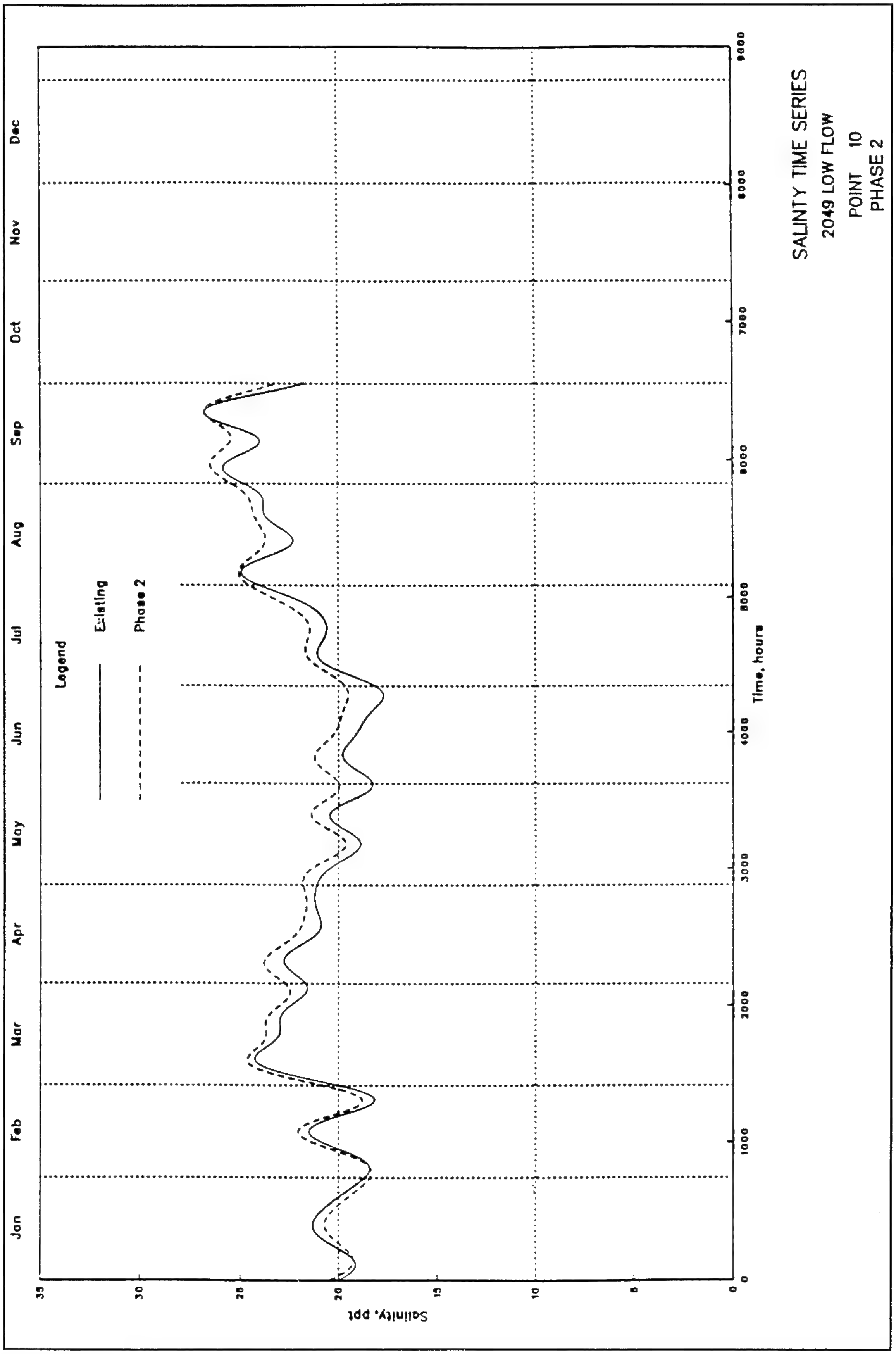
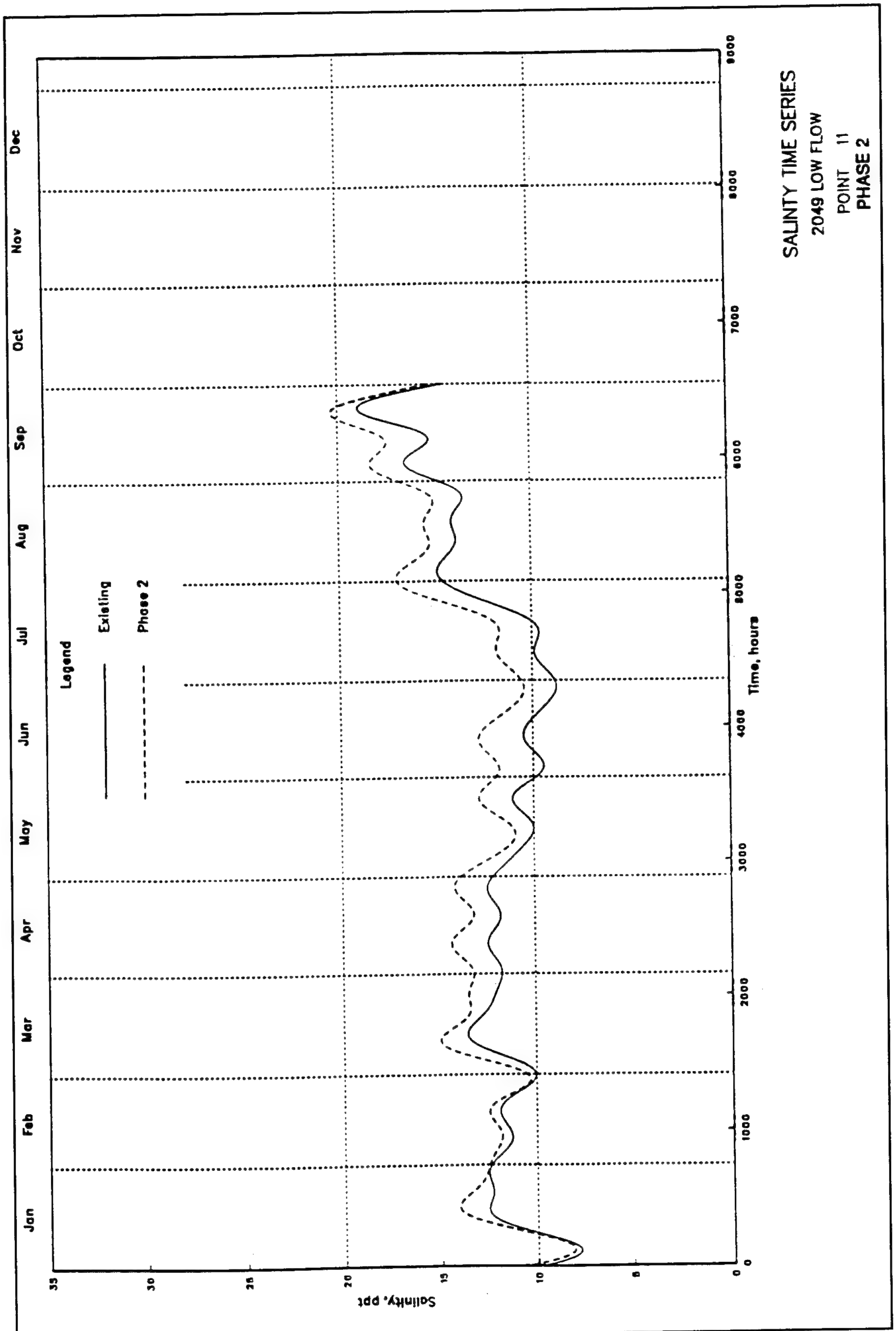
Plate 233



SALINTY TIME SERIES
2049 LOW FLOW
POINT 10
PHASE 2

Plate 234



SALINTY TIME SERIES
2049 LOW FLOW
POINT 11
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
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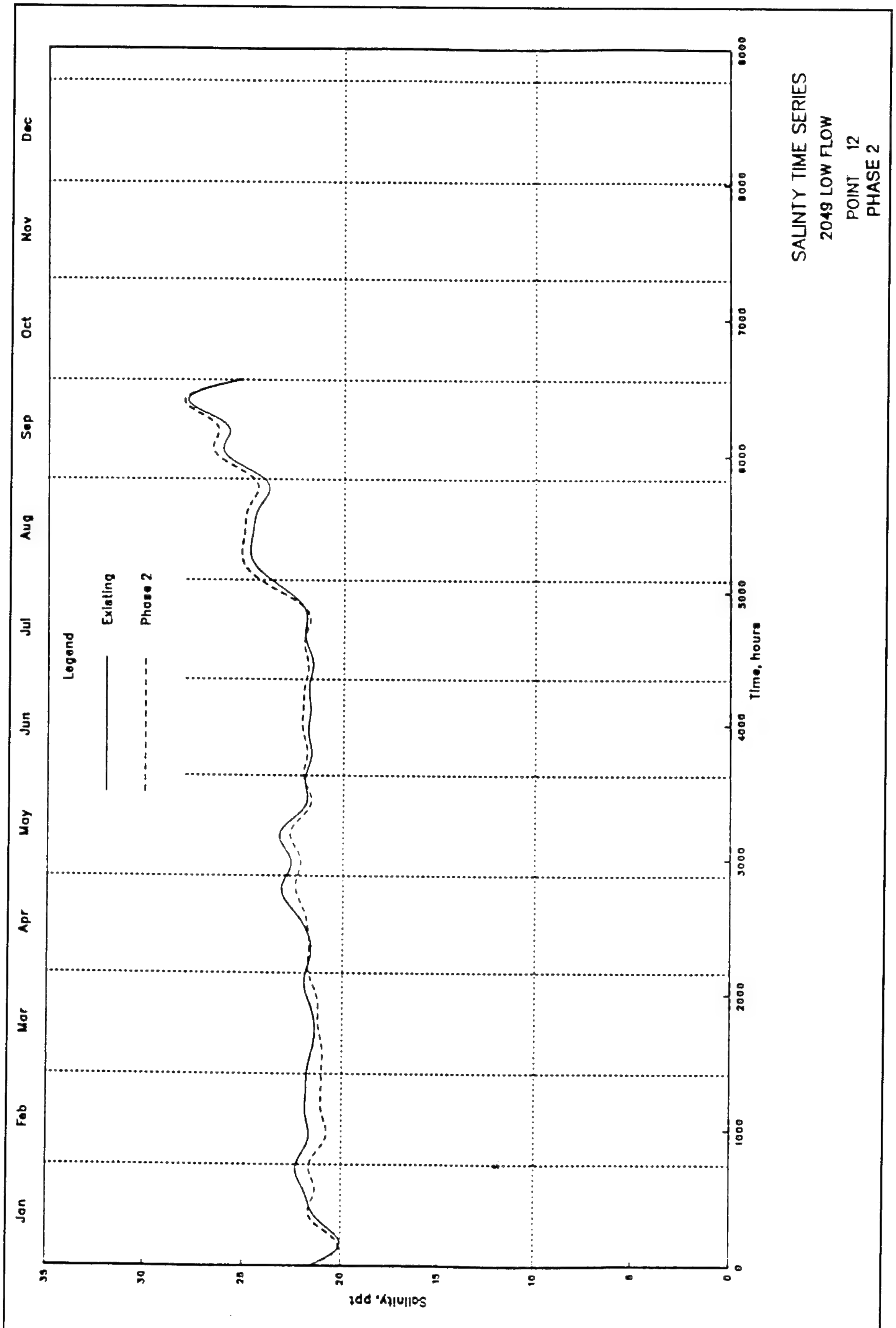
SALINTY TIME SERIES
2049 LOW FLOW
POINT 12
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
Jan
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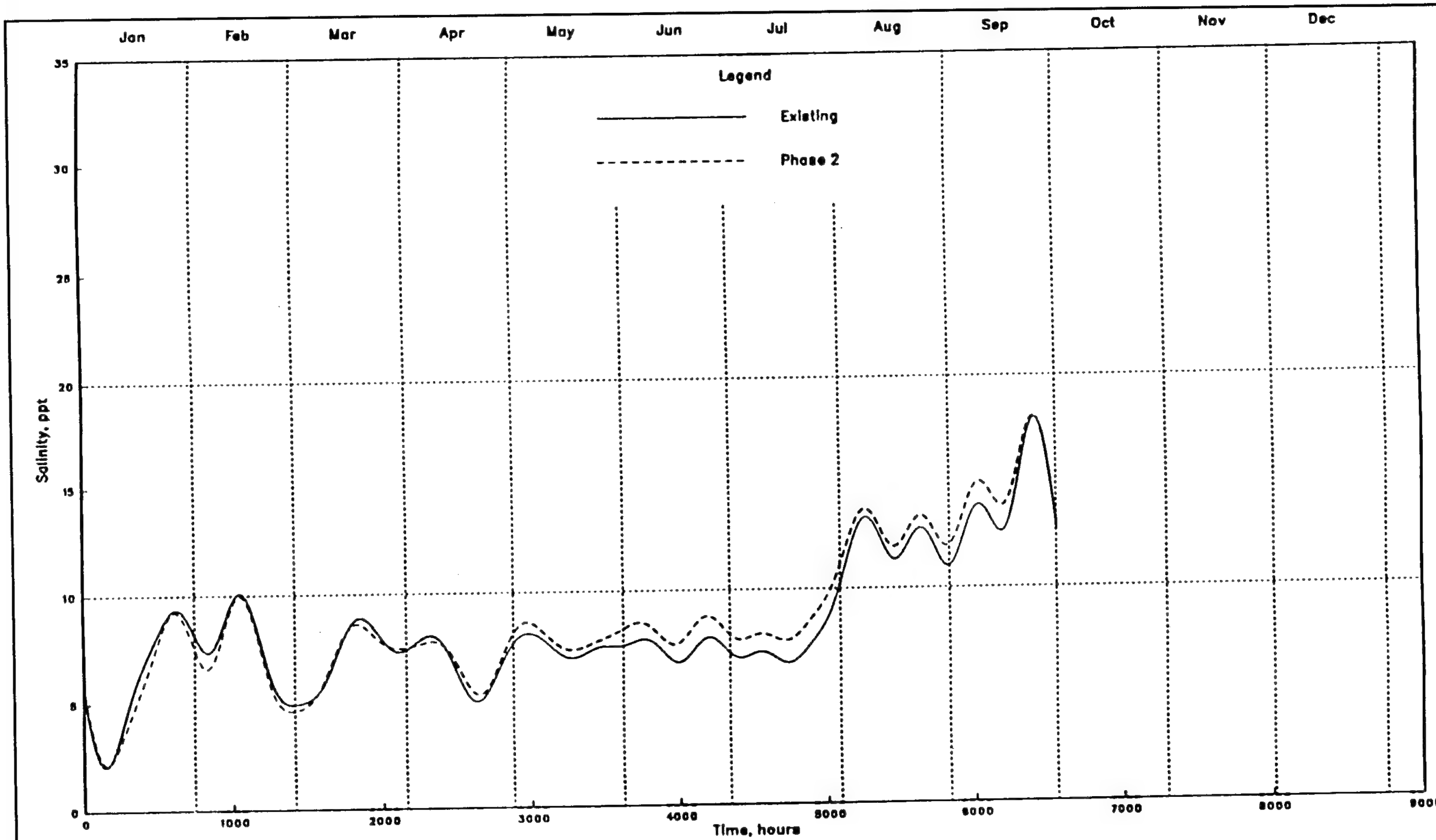
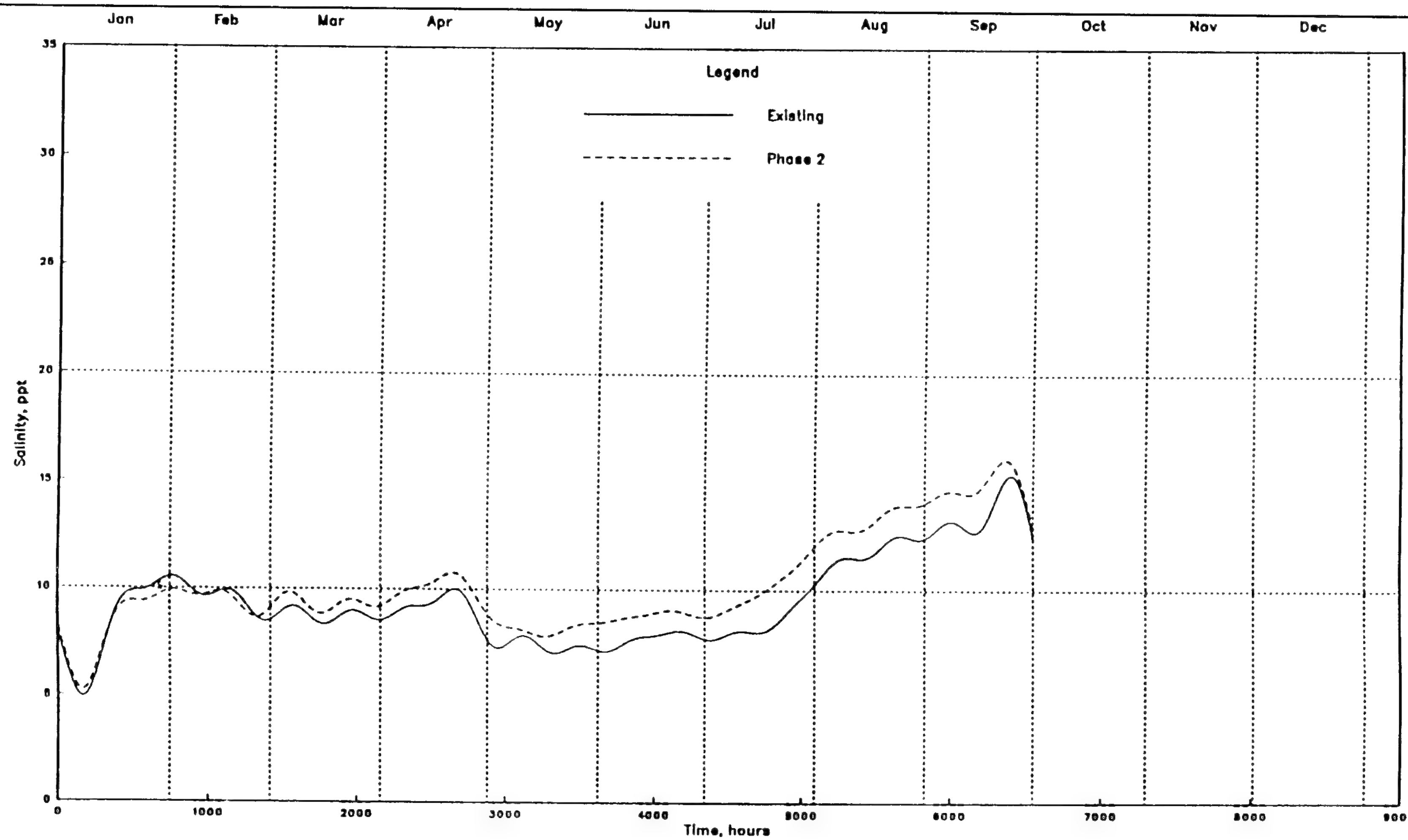
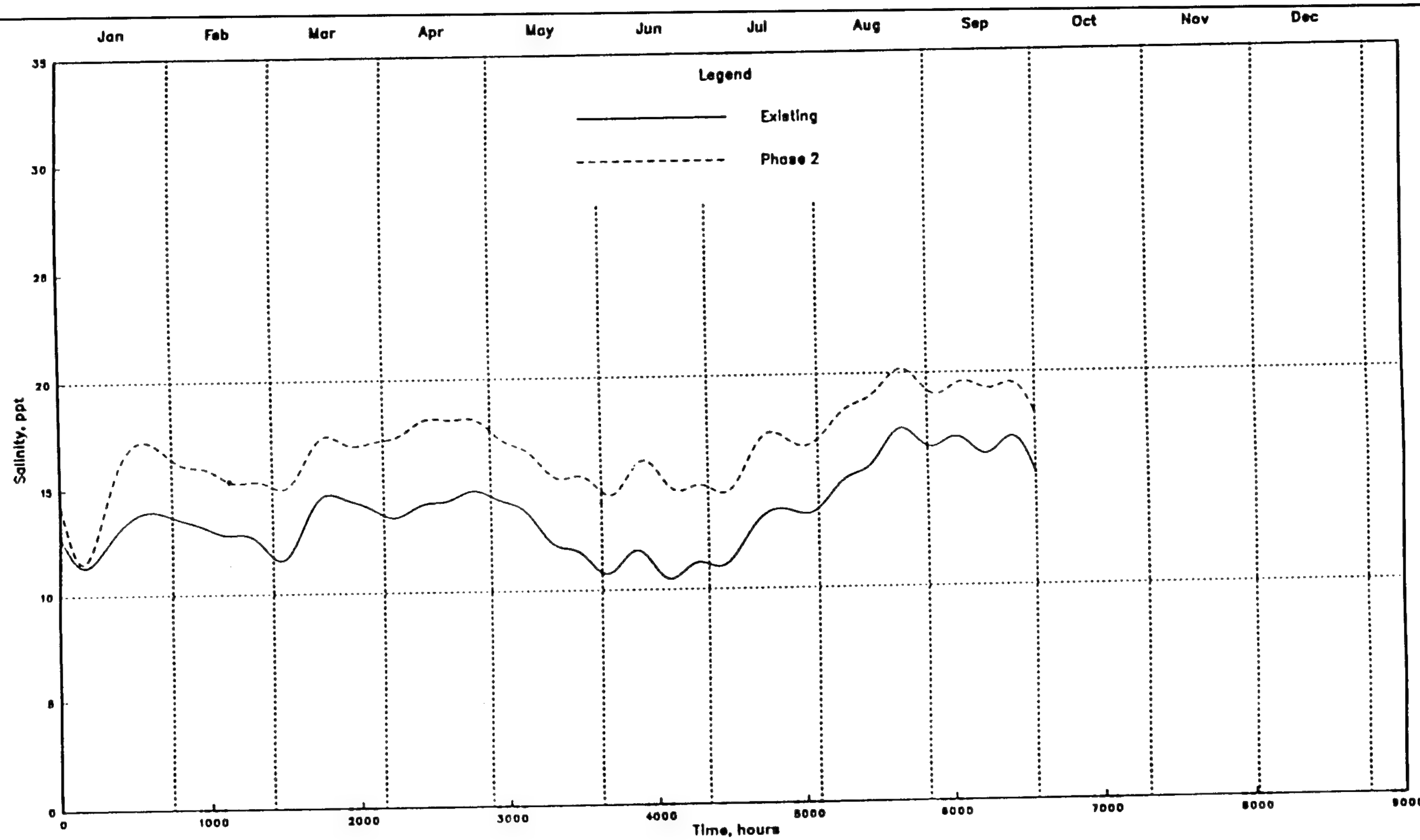


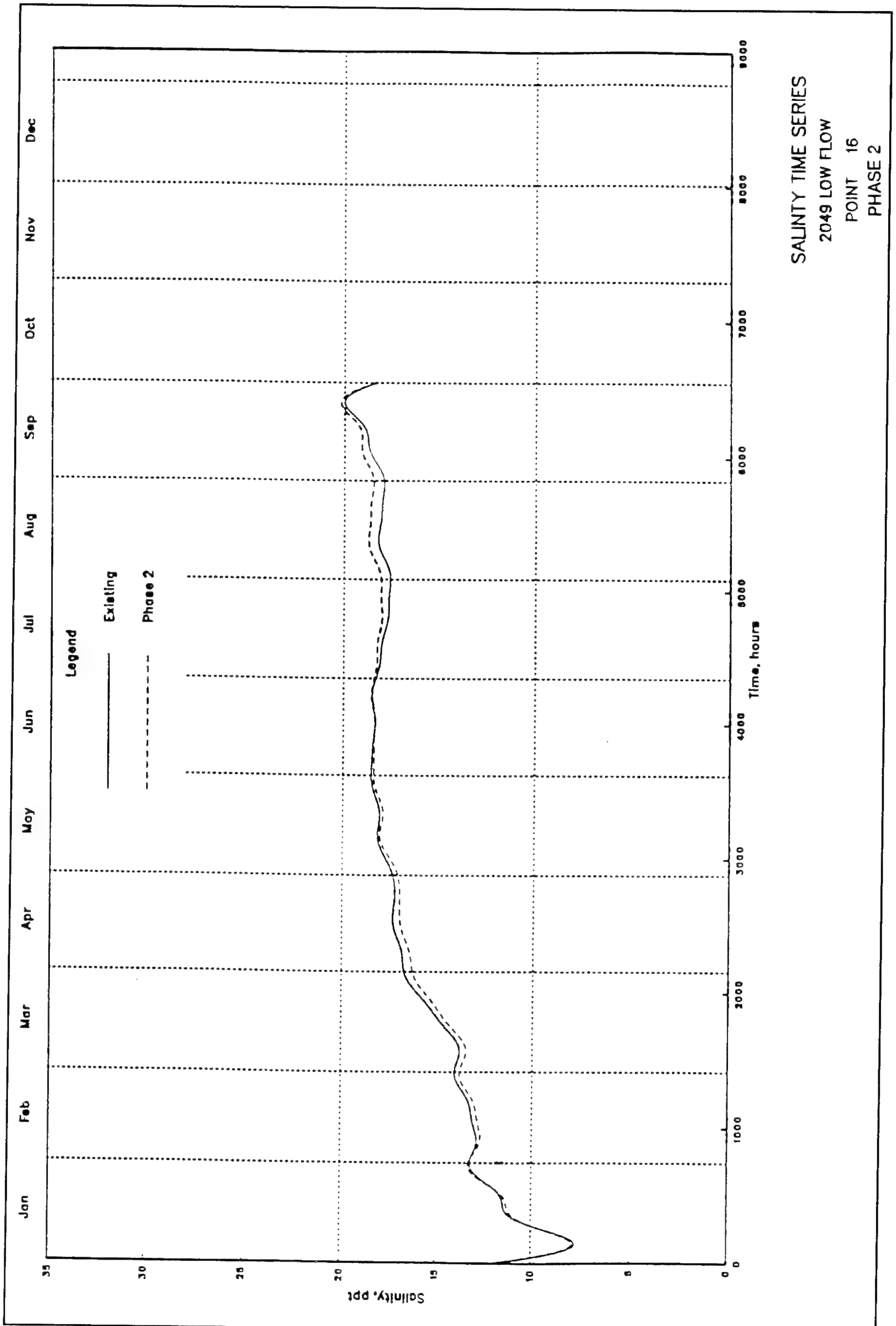
SALINTY TIME SERIES
2049 LOW FLOW
POINT 13
PHASE 2



SALINTY TIME SERIES
2049 LOW FLOW
POINT 14
PHASE 2



SALINTY TIME SERIES
2049 LOW FLOW
POINT 15
PHASE 2


SALINTY TIME SERIES
2049 LOW FLOW
POINT 16
PHASE 2
Legend
Existing
Phase 2
Jan
Feb
Mar
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May
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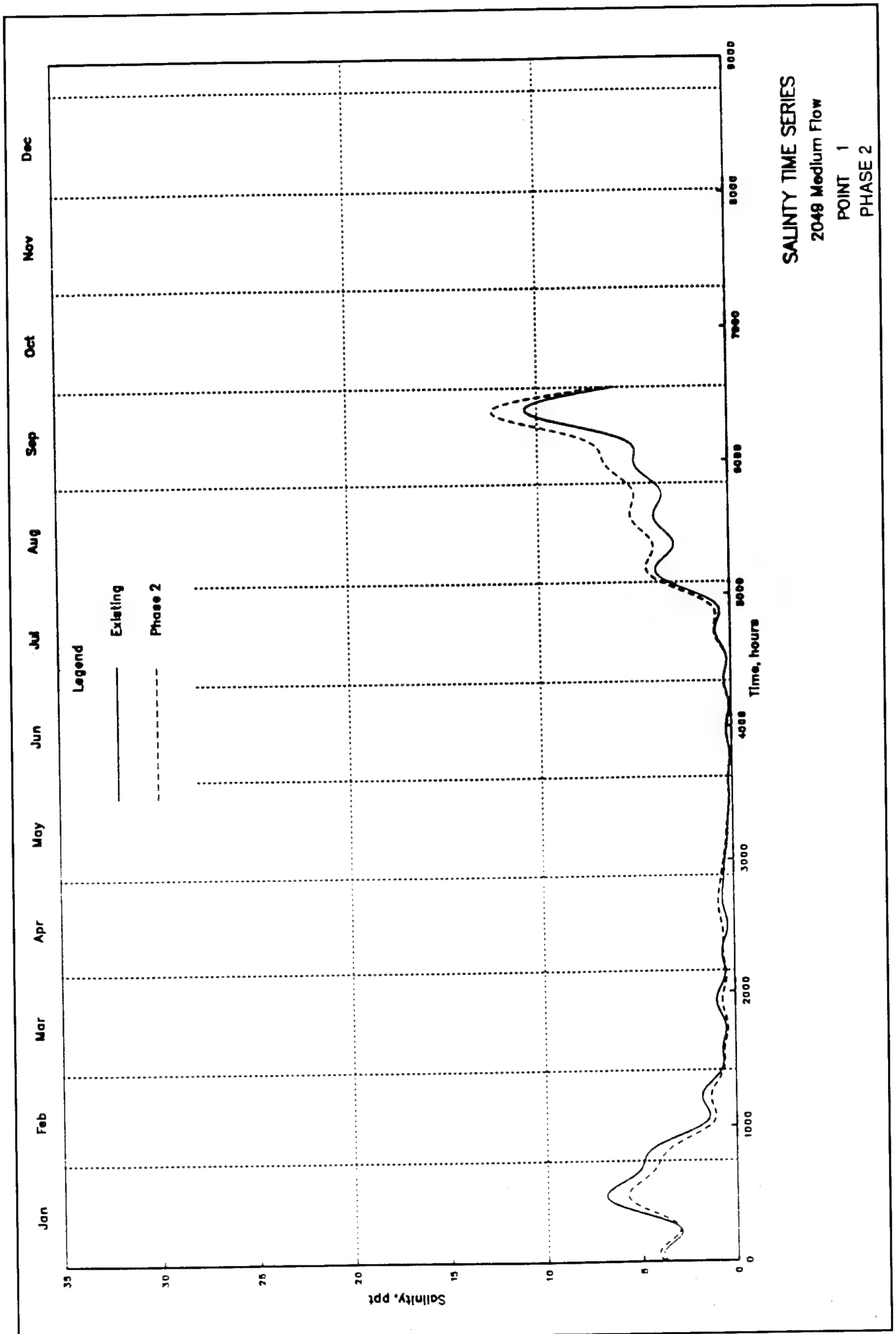
Sep
Oct
Nov
Dec
Time, hours
Salinity, ppt



SALINTY TIME SERIES
2048 Medium Flow
POINT 1
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
Jan
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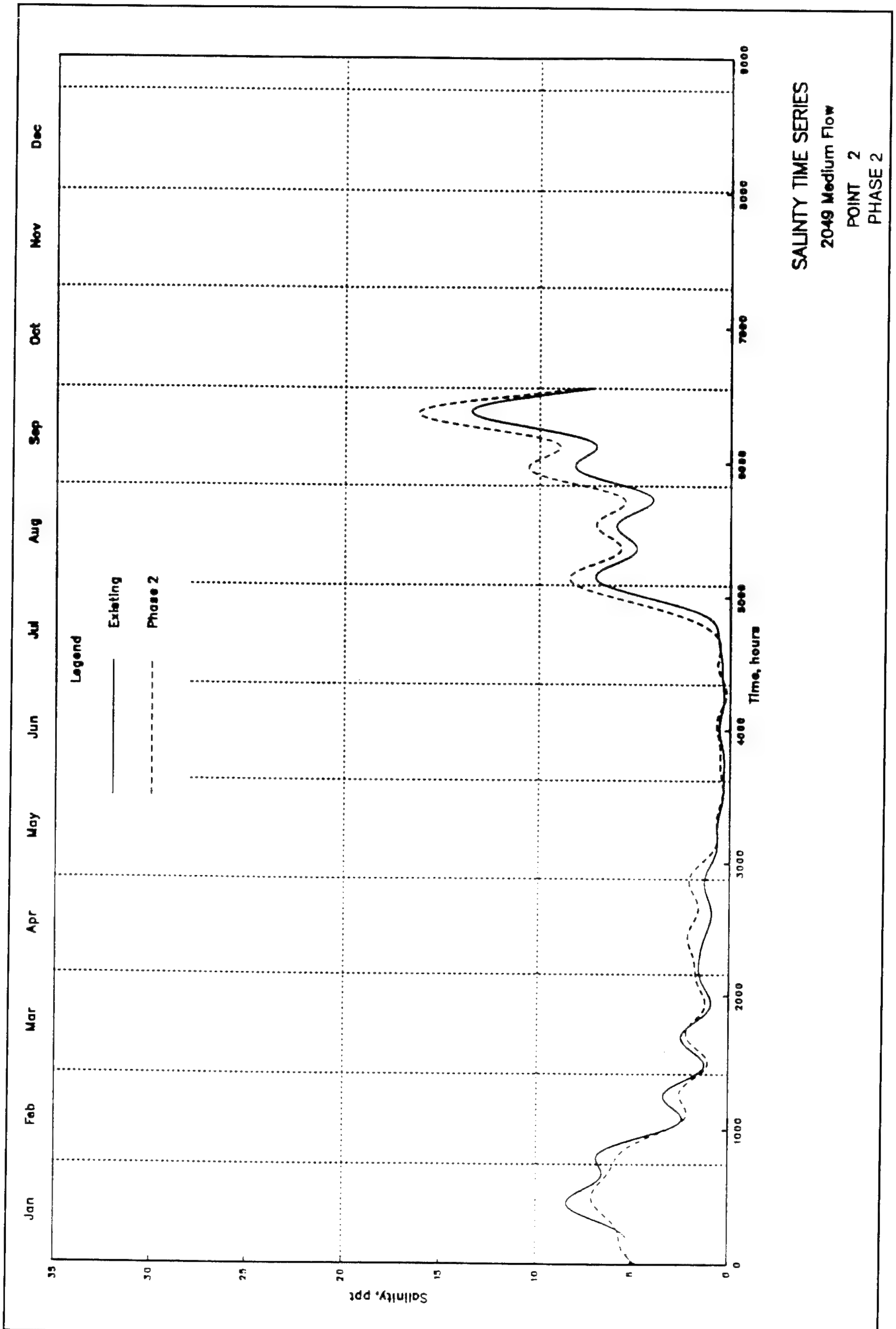
SALINTY TIME SERIES
2049 Medium Flow
POINT 2
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
Jan
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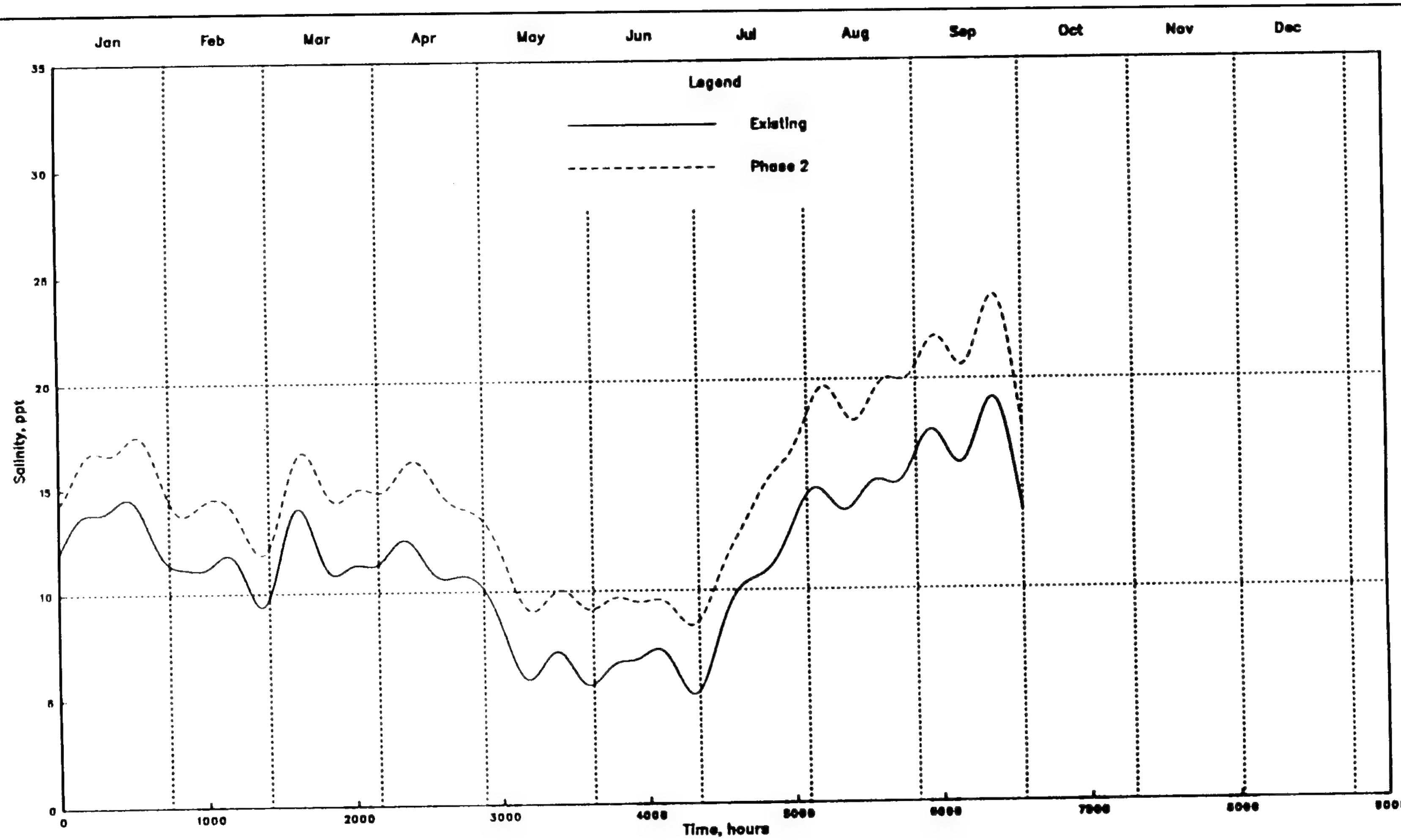
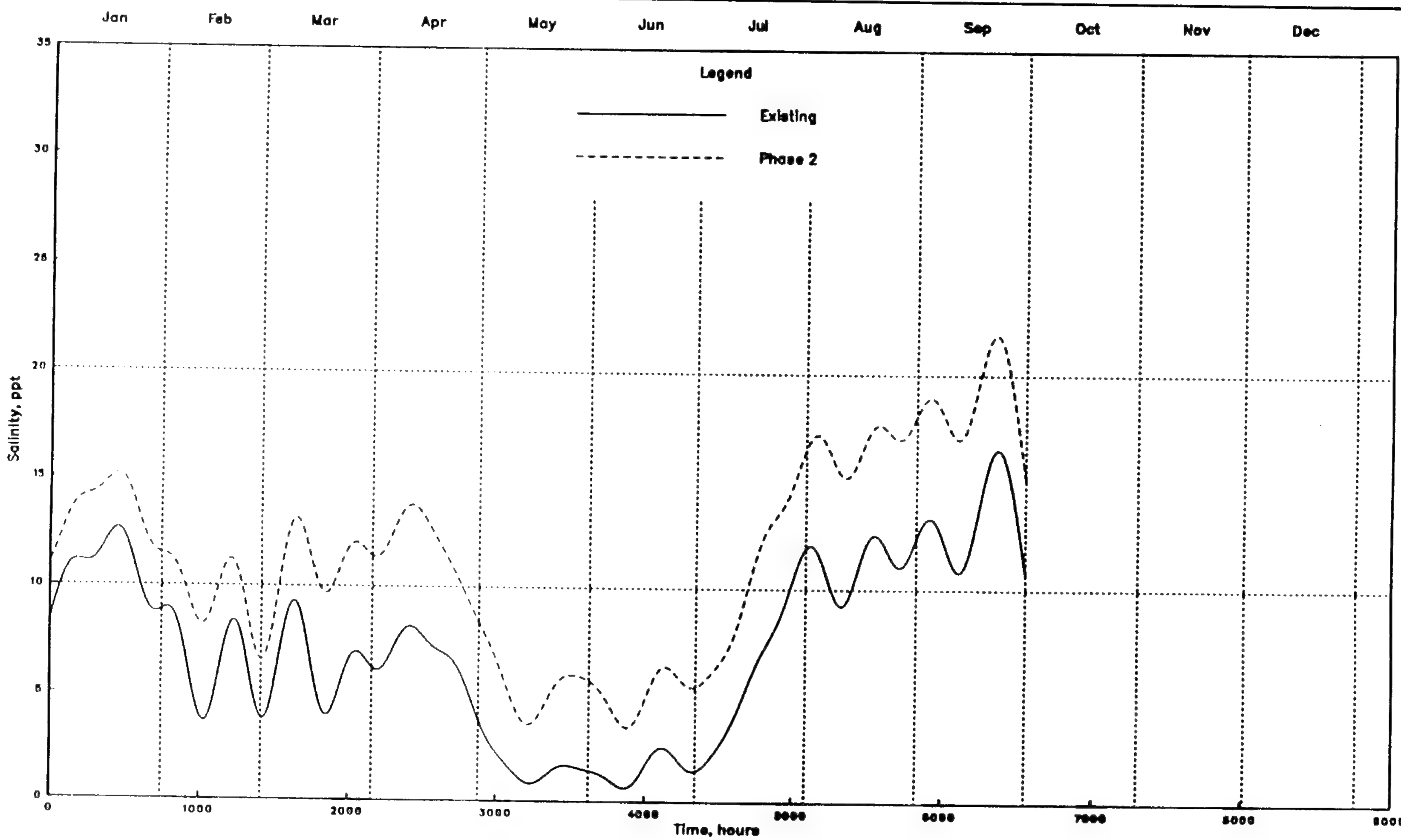
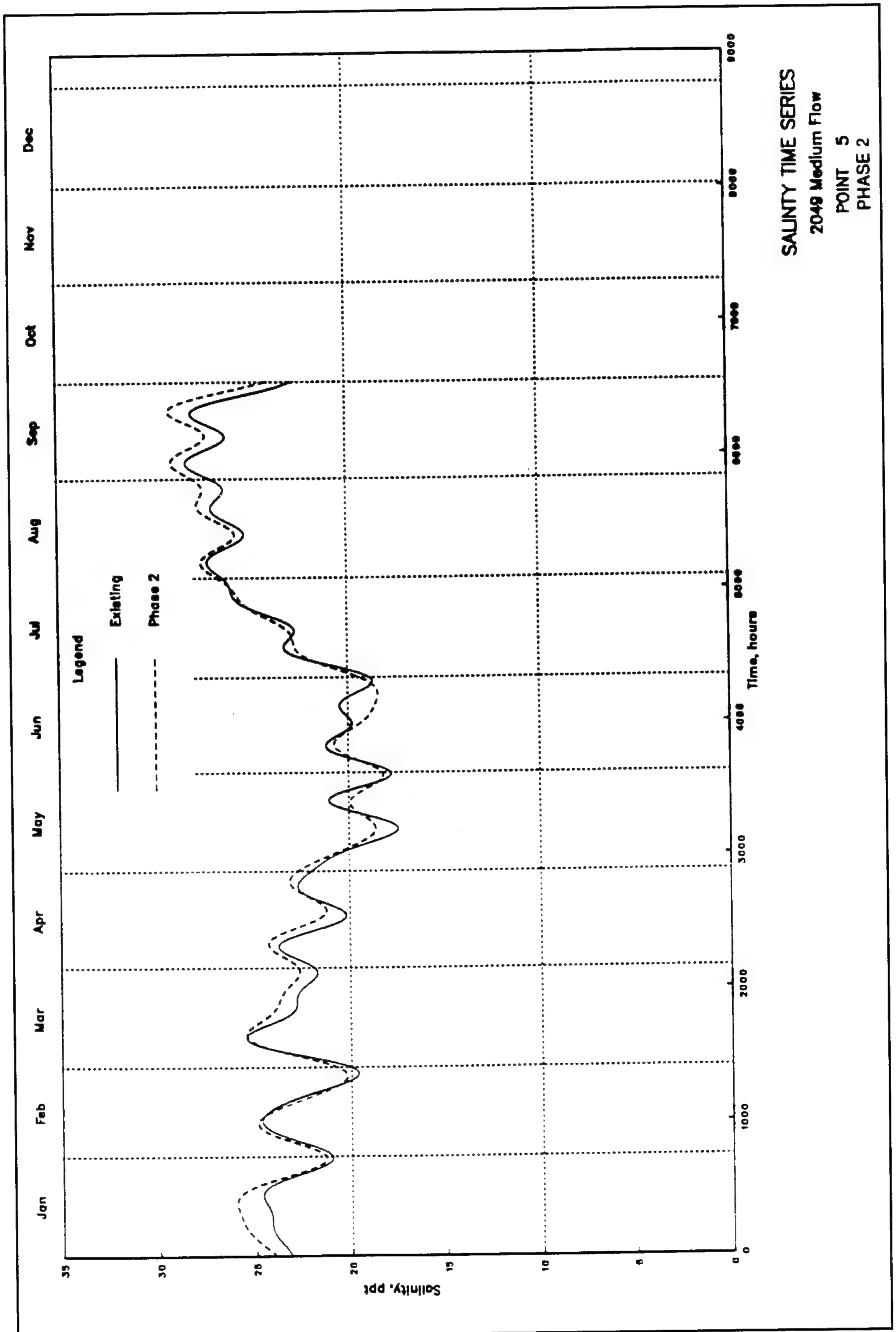


SALINTY TIME SERIES
2049 Medium Flow
POINT 3
PHASE 2



SALINTY TIME SERIES
2049 Medium Flow
POINT 4
PHASE 2

Plate 244


SALINTY TIME SERIES
2049 Medium Flow
POINT 5
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
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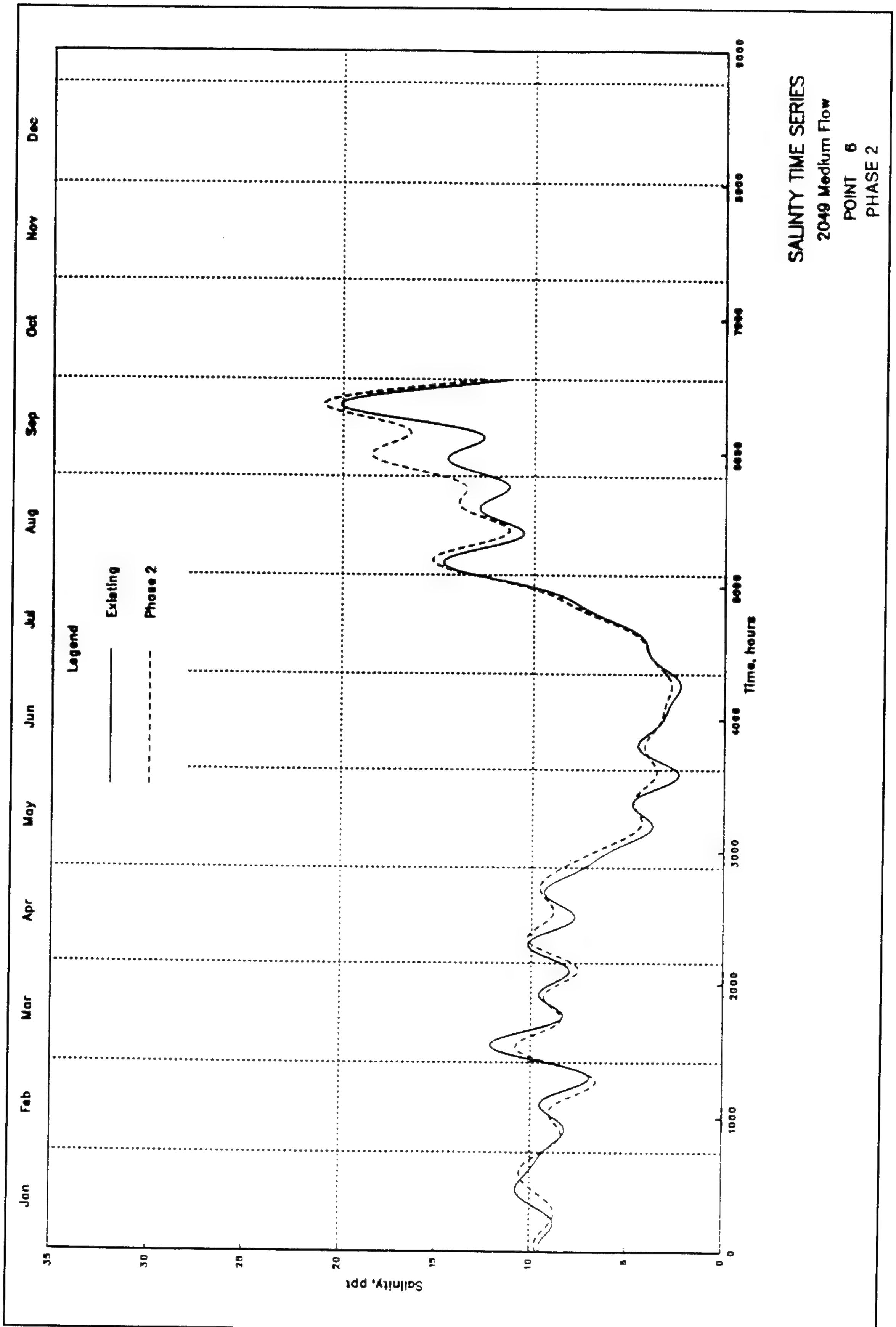

SALINTY TIME SERIES
2048 Medium Flow
POINT 8
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
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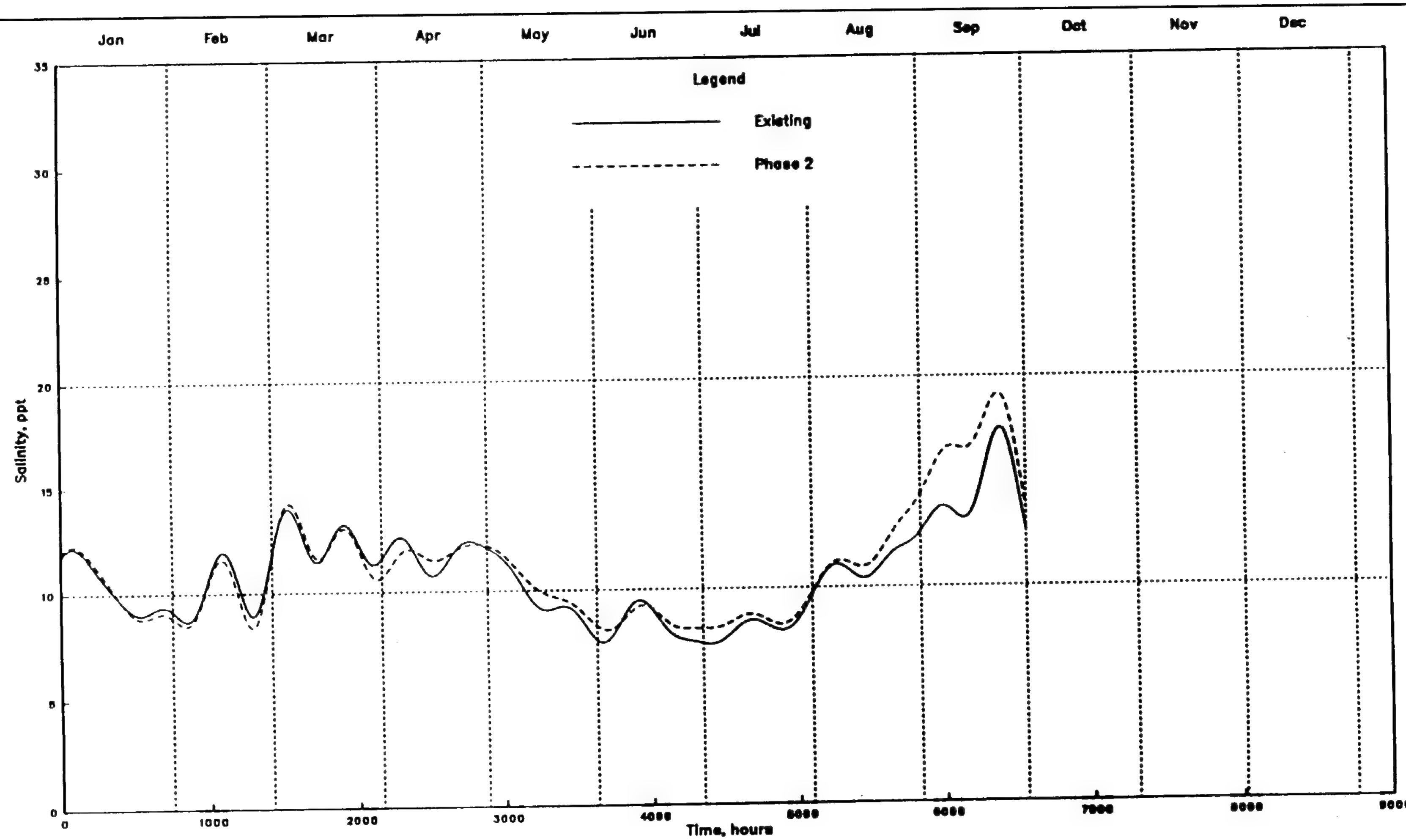
Plate 246

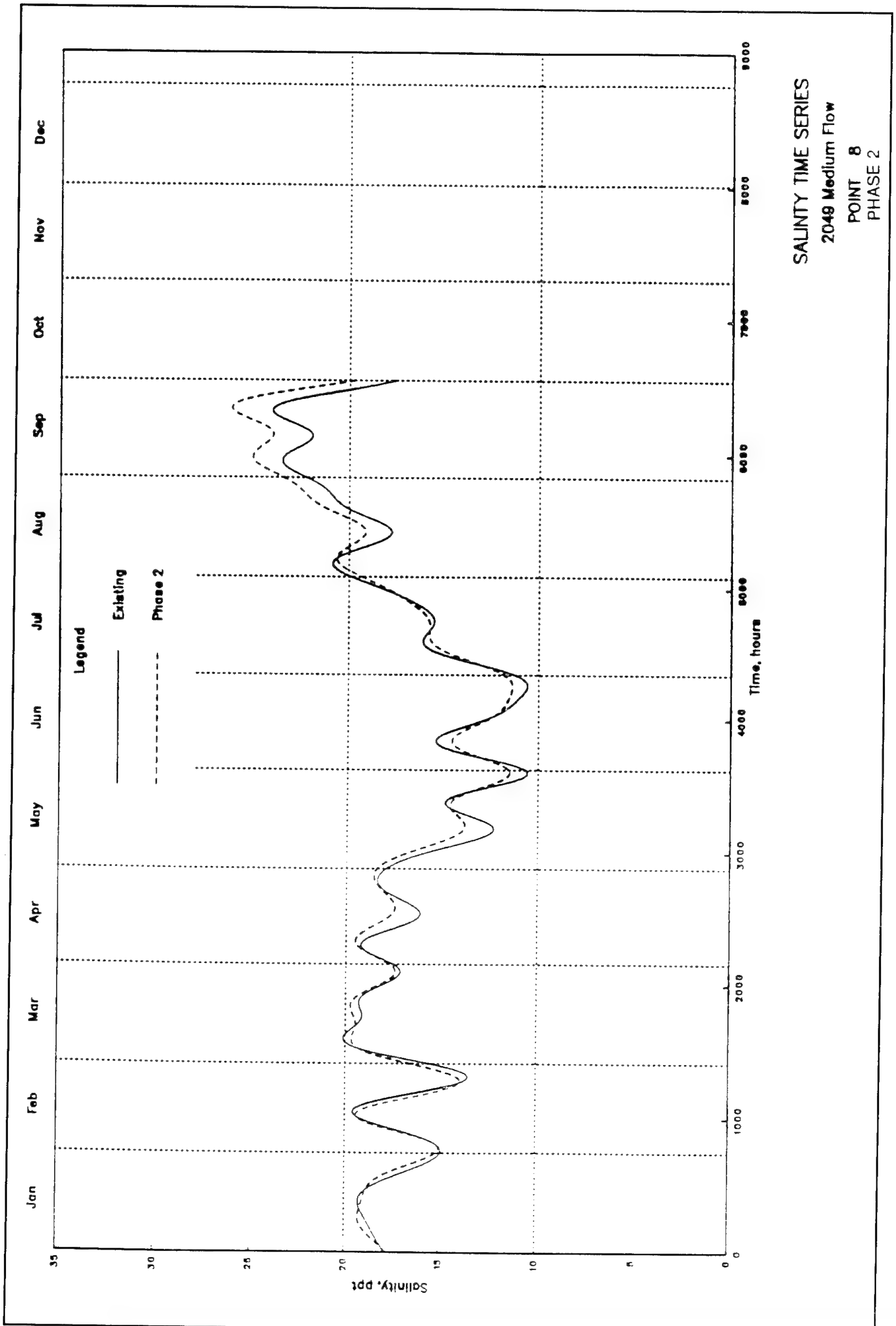


SALINTY TIME SERIES

2049 Medium Flow

POINT 7

PHASE 2



SALINTY TIME SERIES
2049 Medium Flow
POINT 8
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
Jan
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Plate 248

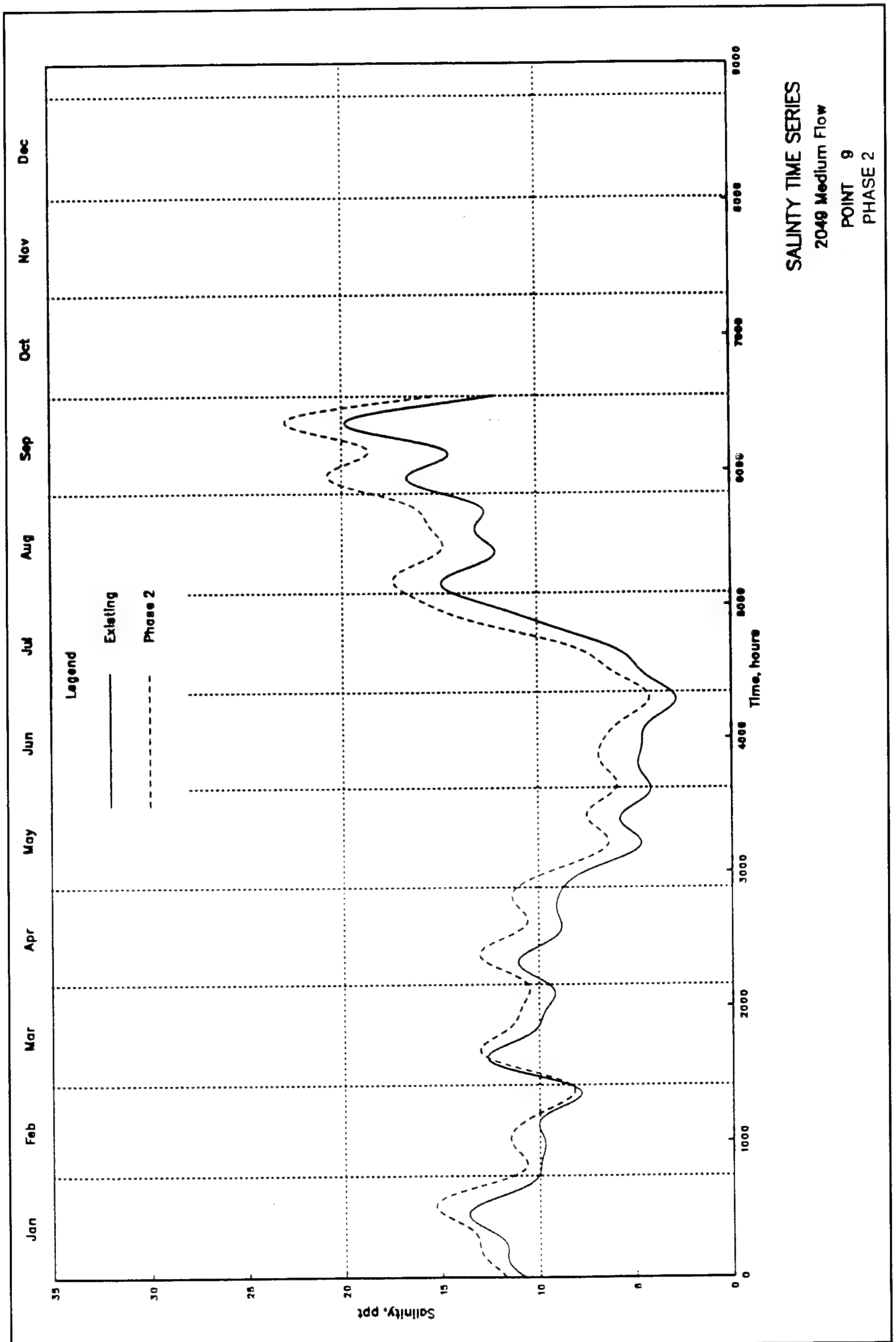
SALINTY TIME SERIES
2049 Medium Flow
POINT 9
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
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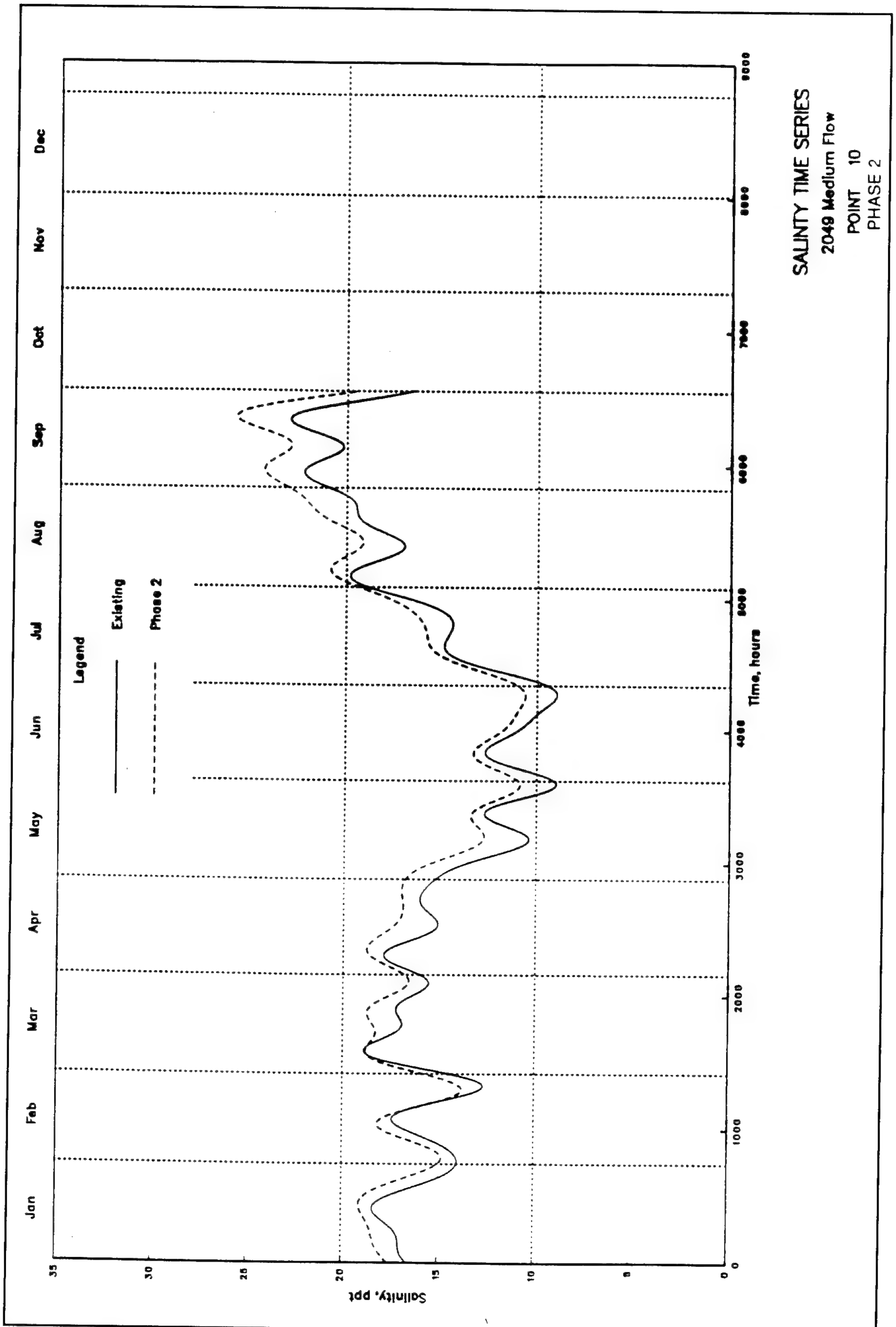
Plate 249



SALINTY TIME SERIES
2049 Medium Flow
POINT 10
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
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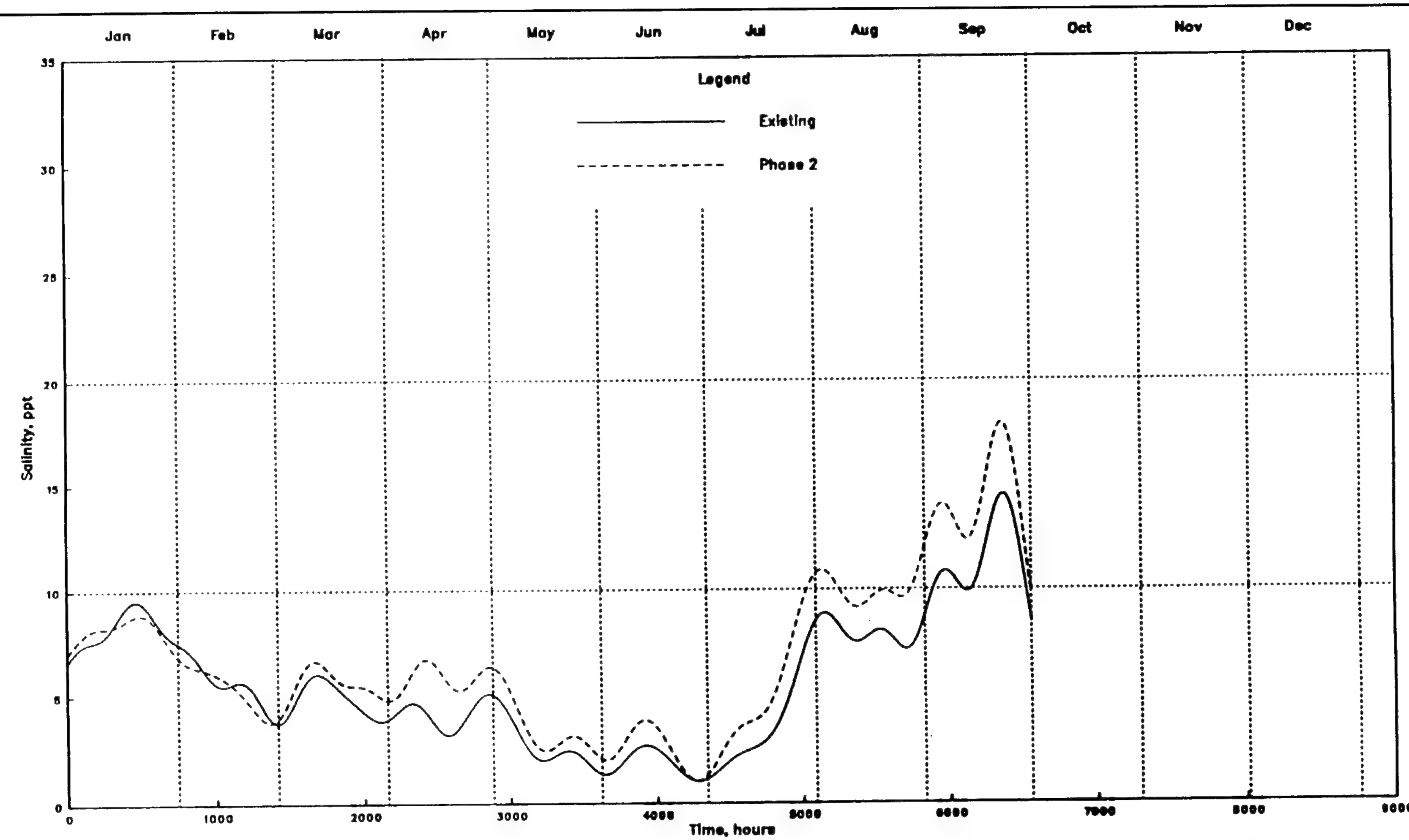

SALINTY TIME SERIES
2049 Medium Flow
POINT 11
PHASE 2

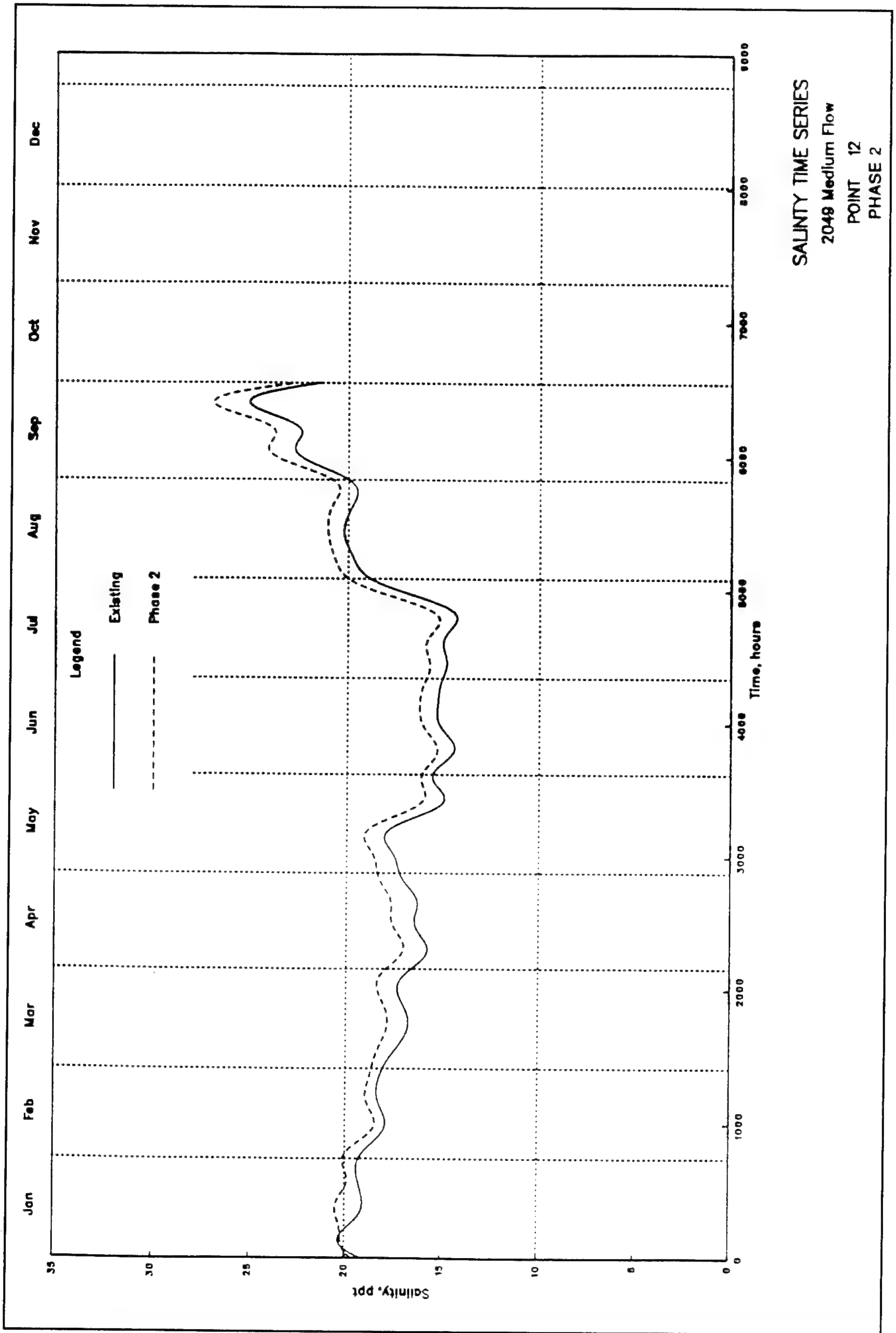
SALINTY TIME SERIES
2048 Medium Flow
POINT 12
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
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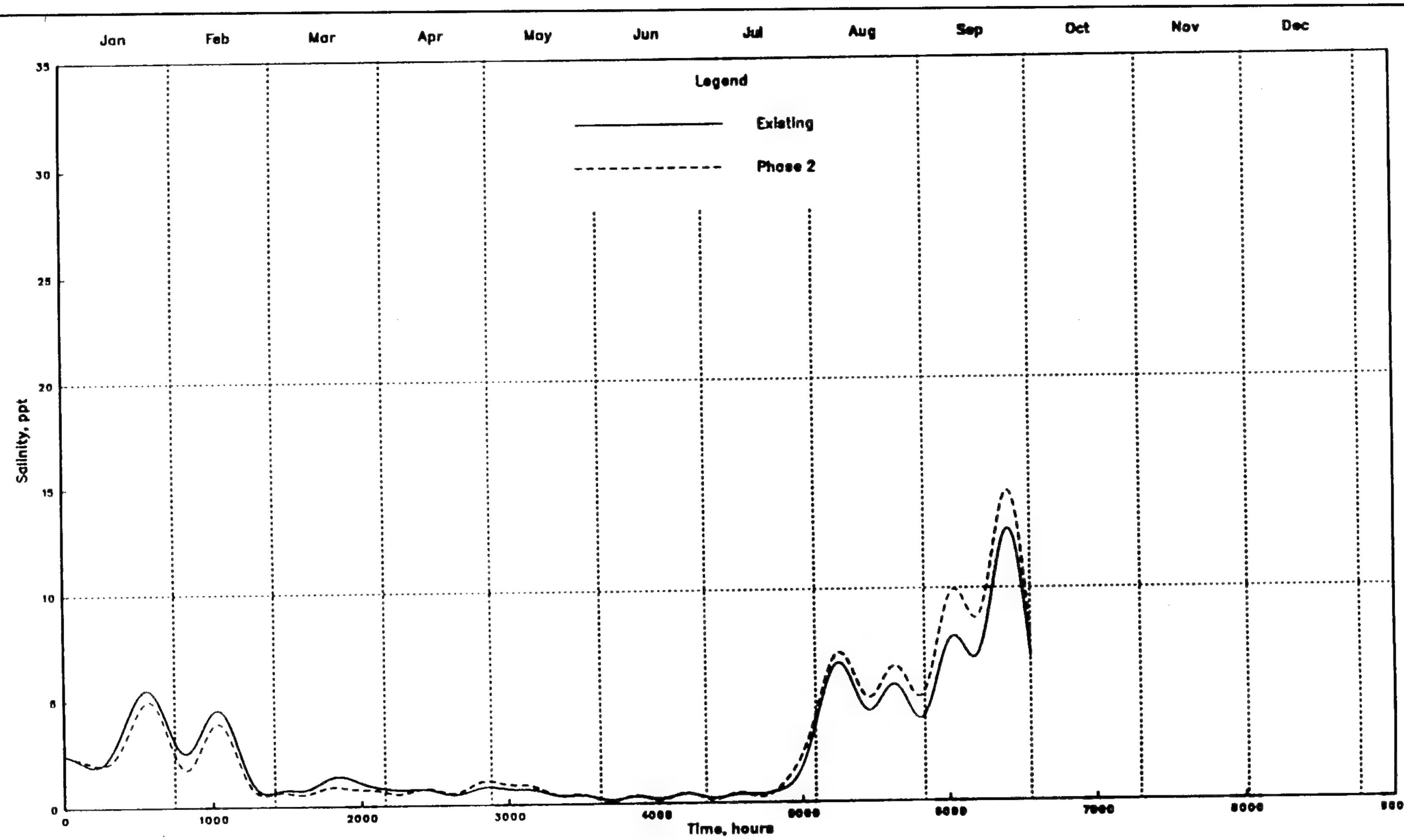
Plate 252



SALINTY TIME SERIES
2049 Medium Flow
POINT 13
PHASE 2

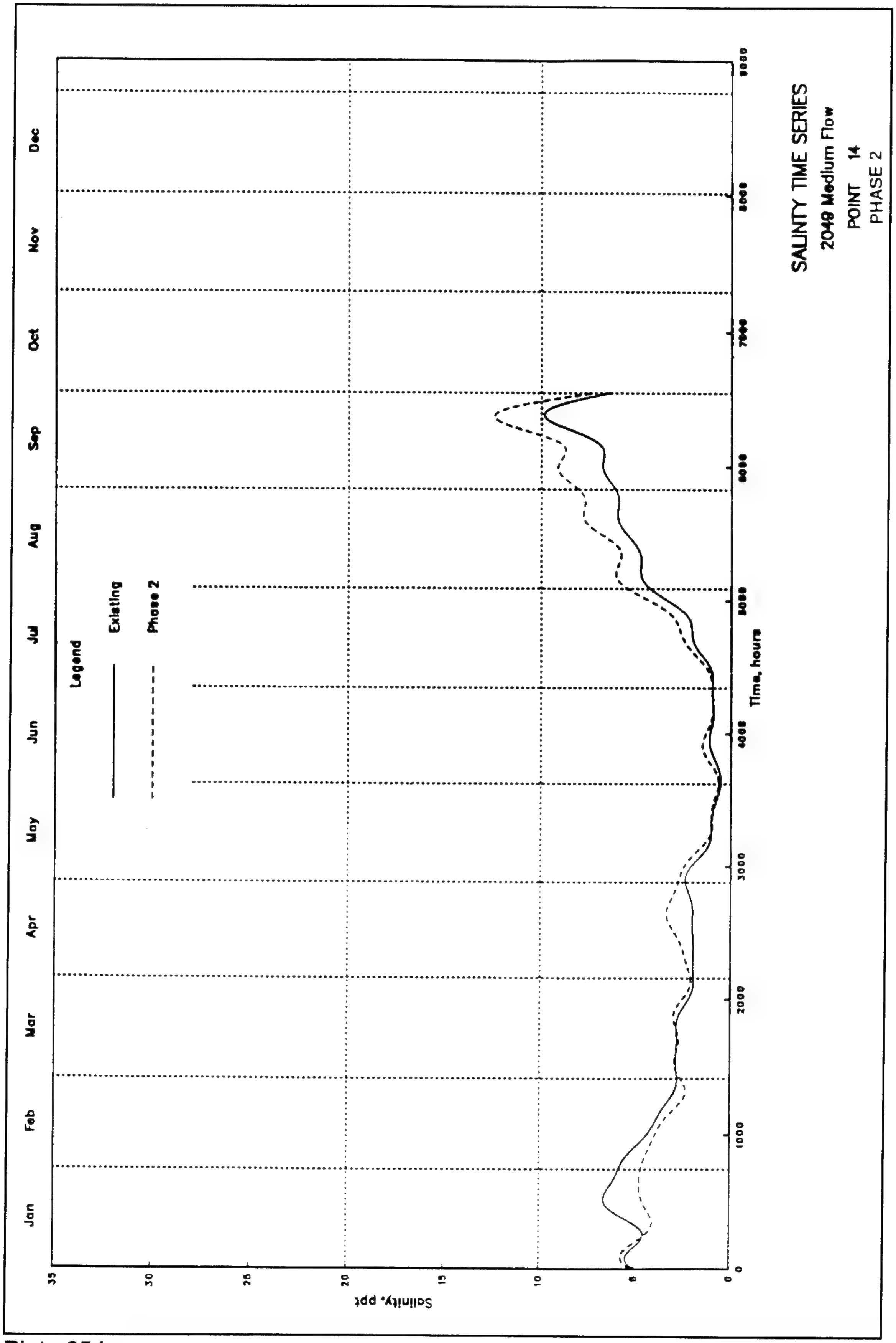

SALINTY TIME SERIES
2049 Medium Flow
POINT 14
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
Jan
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Plate 254

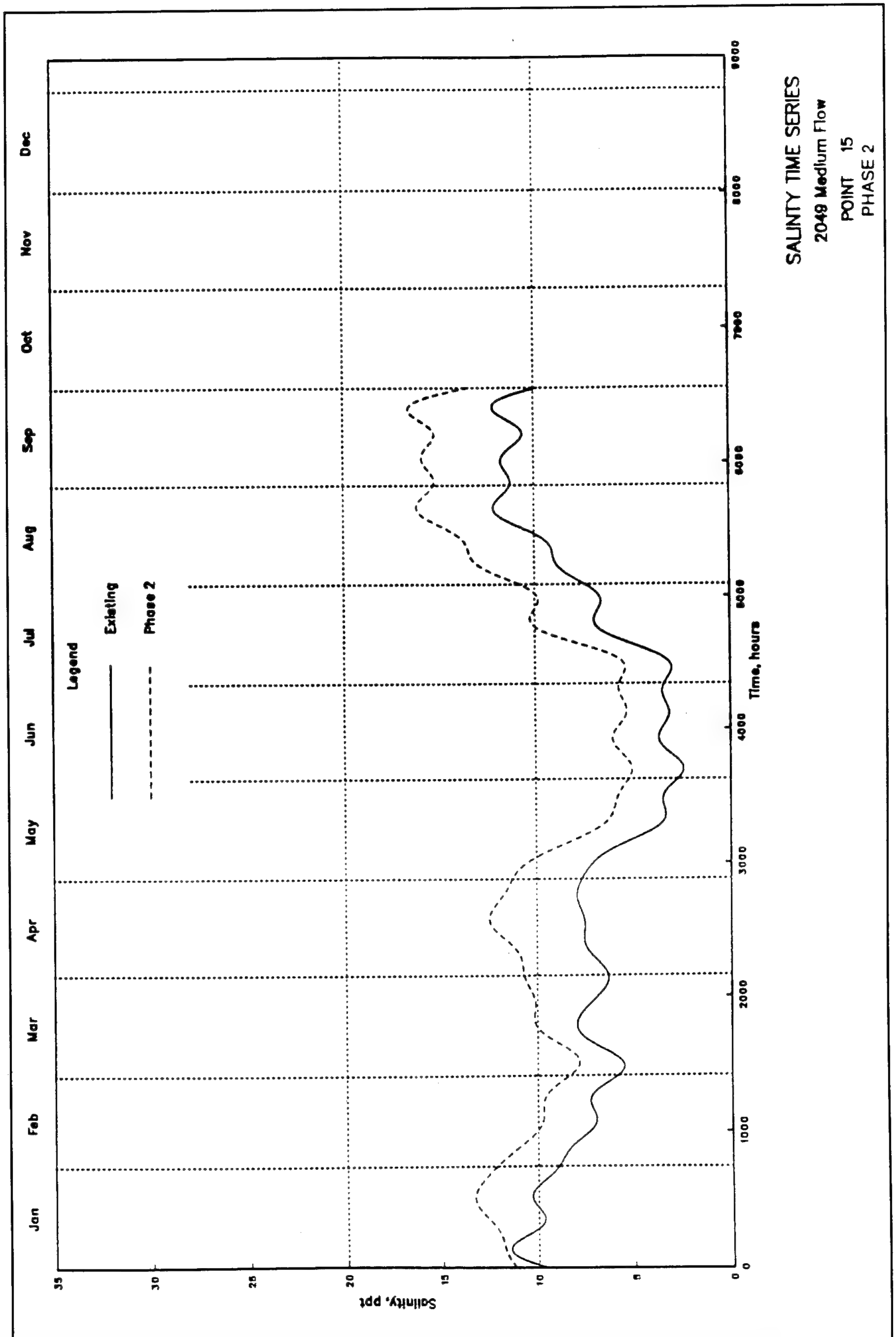
SALINTY TIME SERIES
2049 Medium Flow
POINT 15
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
Jan
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Plate 255

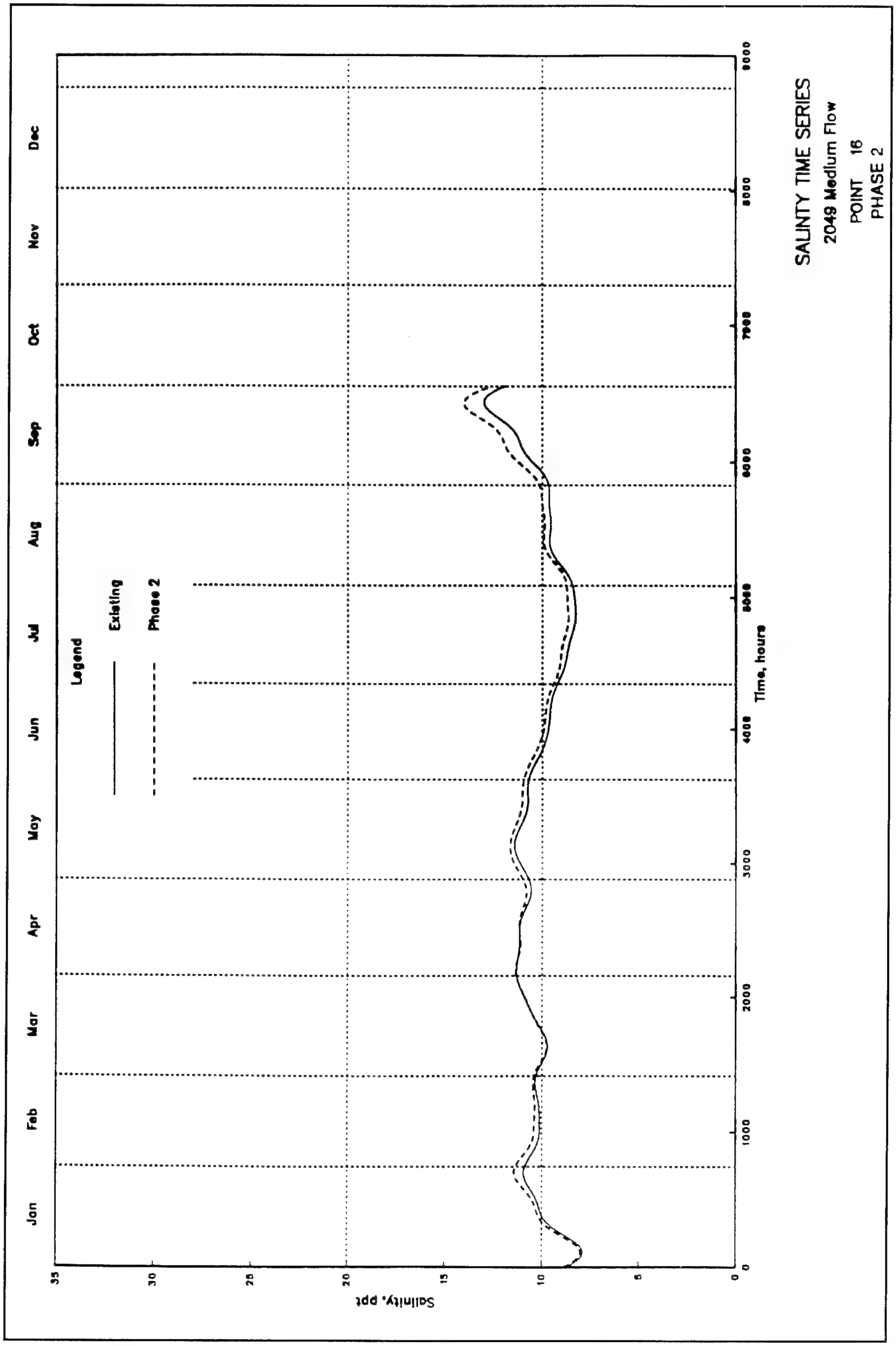
SALINTY TIME SERIES
2049 Medium Flow
POINT 16
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
Jan
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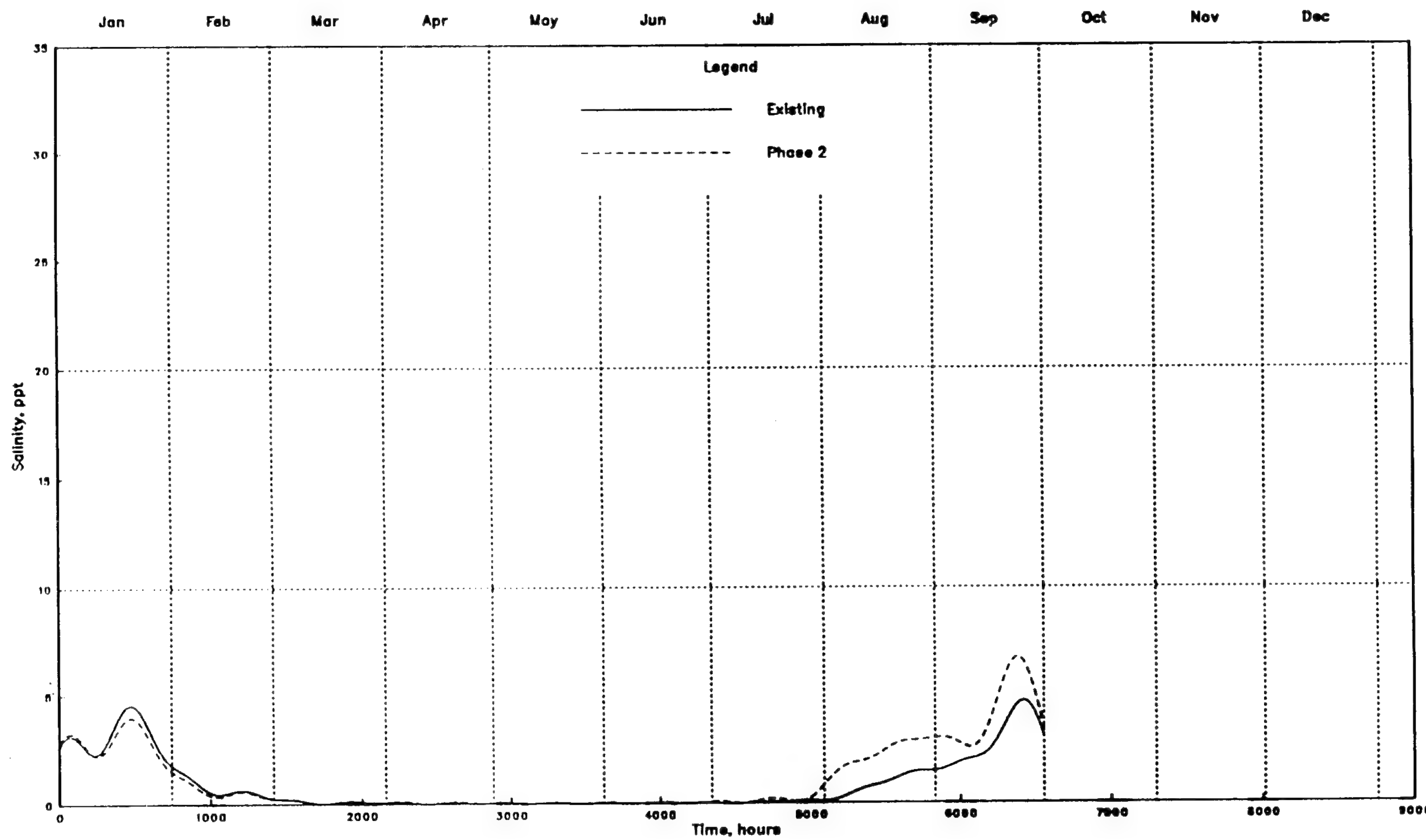
Plate 256



SALINTY TIME SERIES
2049 High Flow
POINT 1
PHASE 2

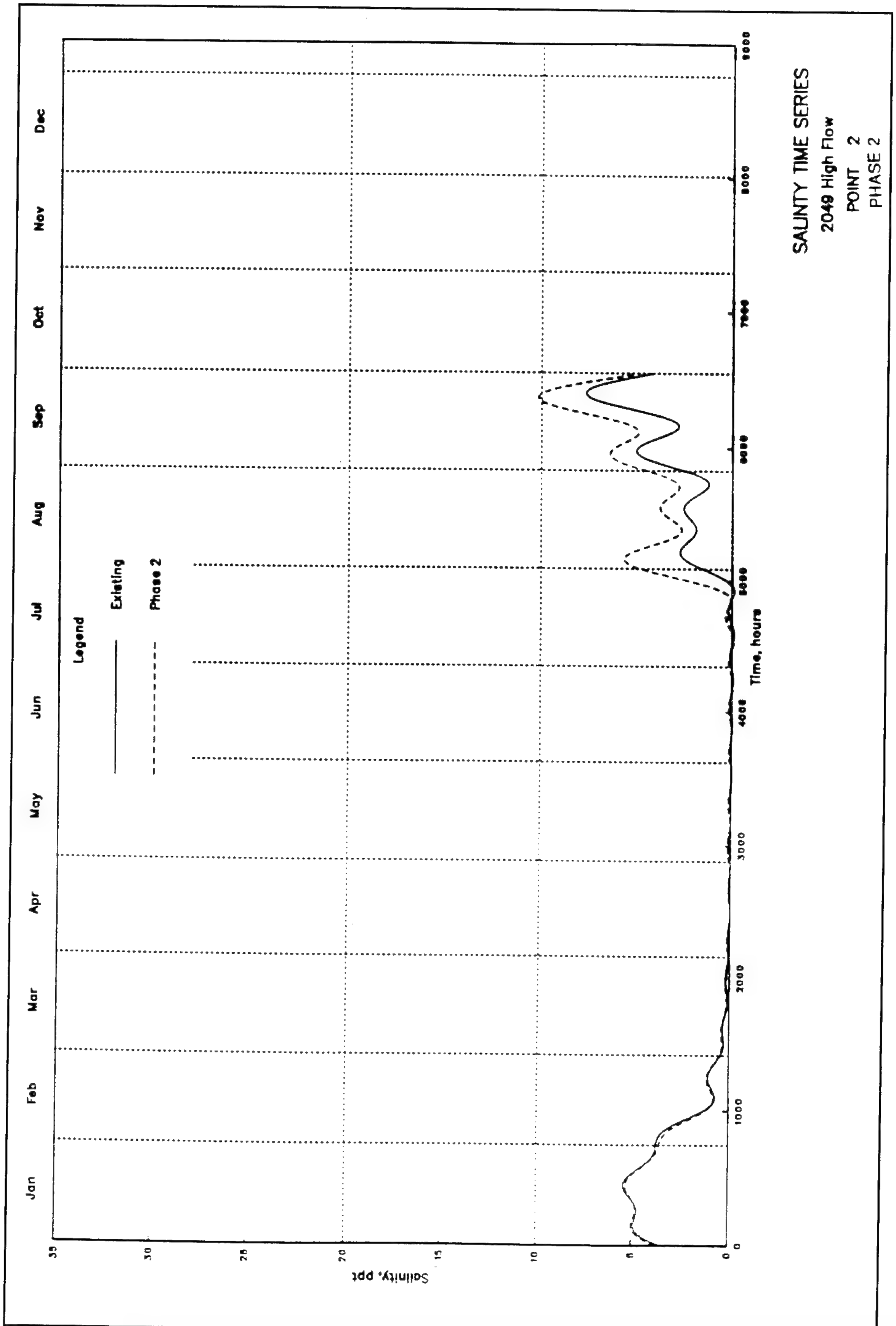

SALINTY TIME SERIES
2049 High Flow
POINT 2
PHASE 2
Legend
Existing
Phase 2
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Time, hours
Salinity, ppt
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
0
5
10
15
20
25
30
35

Plate 258

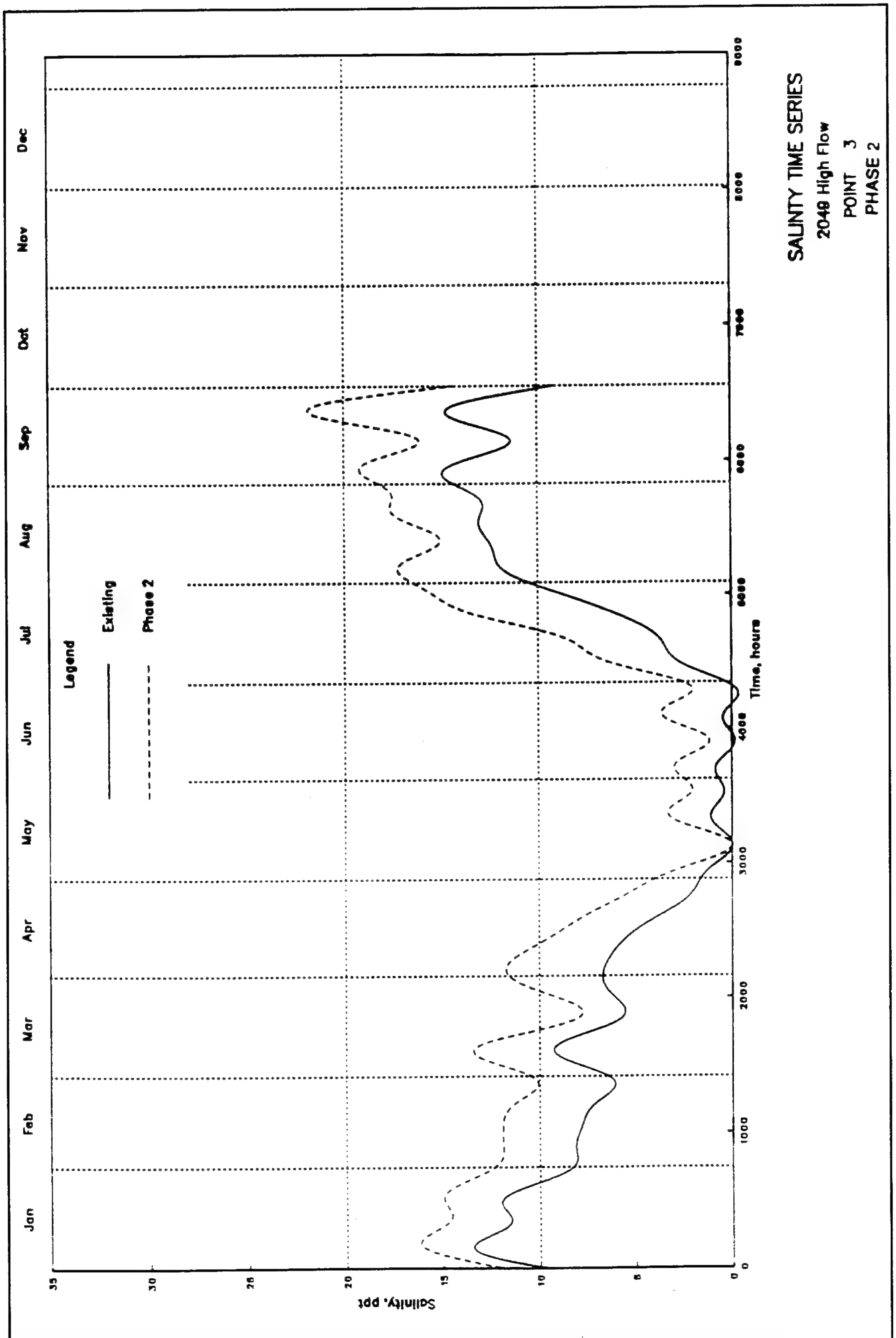
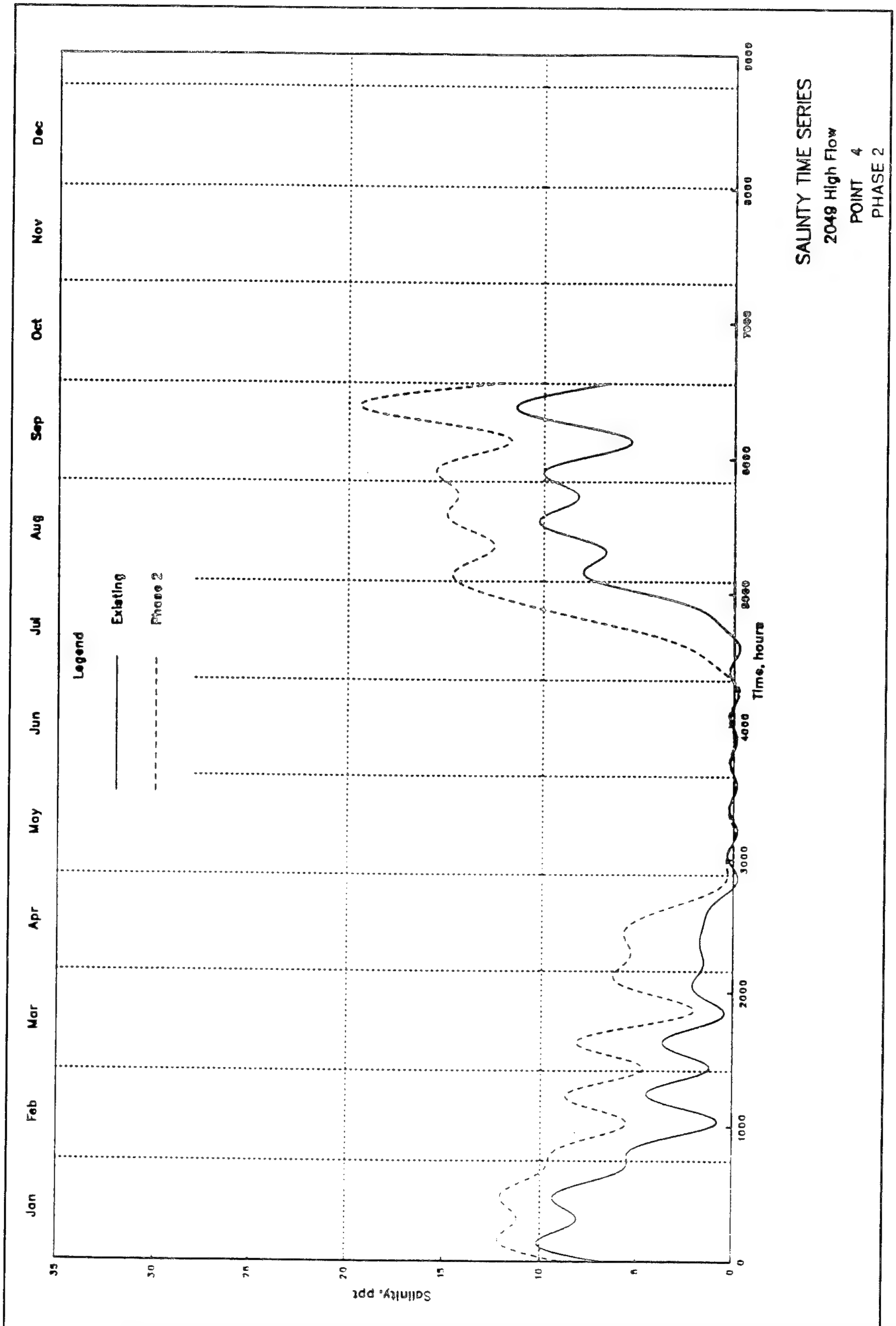

SALINTY TIME SERIES
2048 High Flow
POINT 3
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0
5
10
15
20
25
30
35
0
1000
2000
3000
4000

Plate 259


SALINTY TIME SERIES
2049 High Flow
POINT 4
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
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Oct
Nov
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0
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2000
3000
4000
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10
15
20
30
35

Plate 260

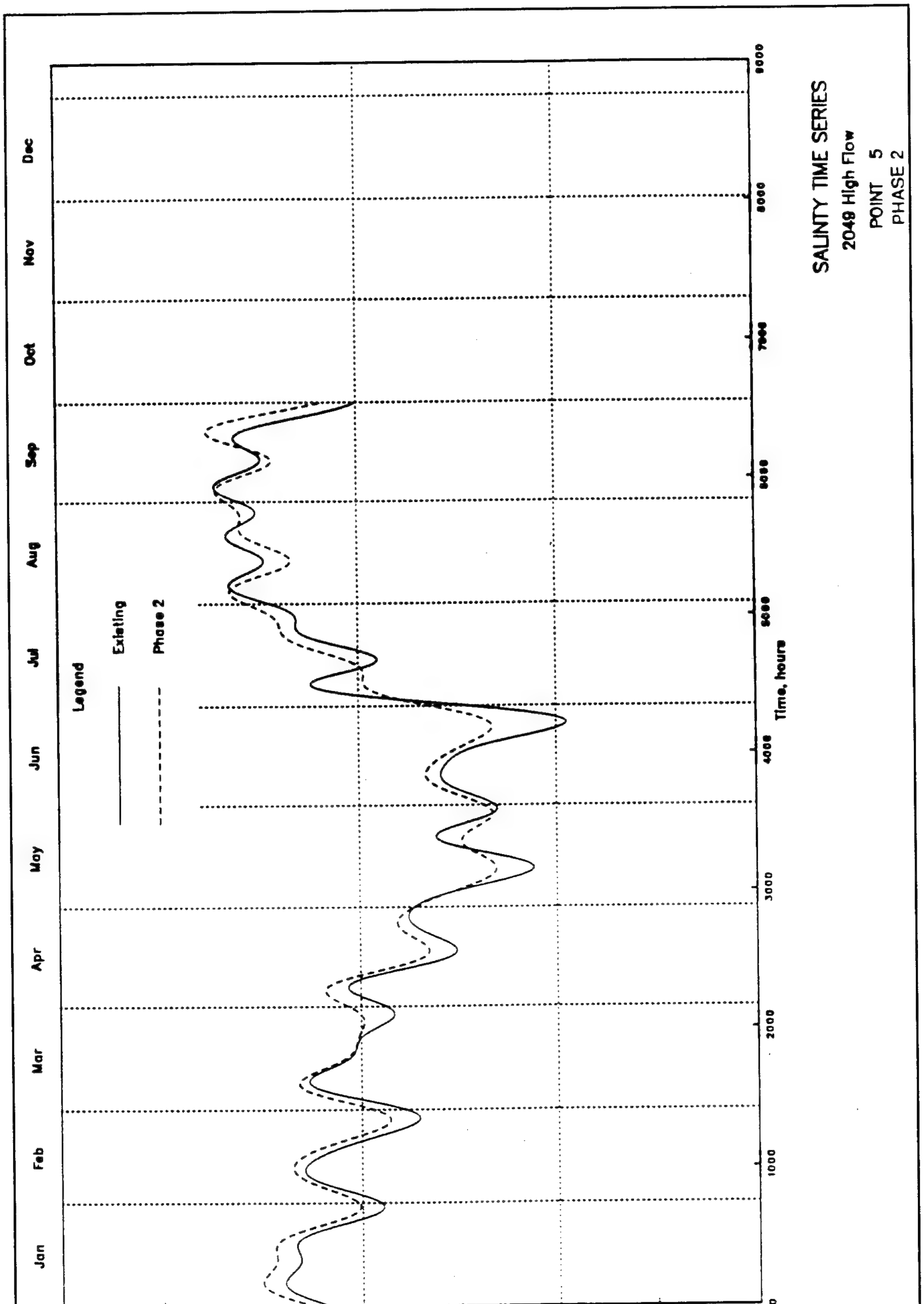
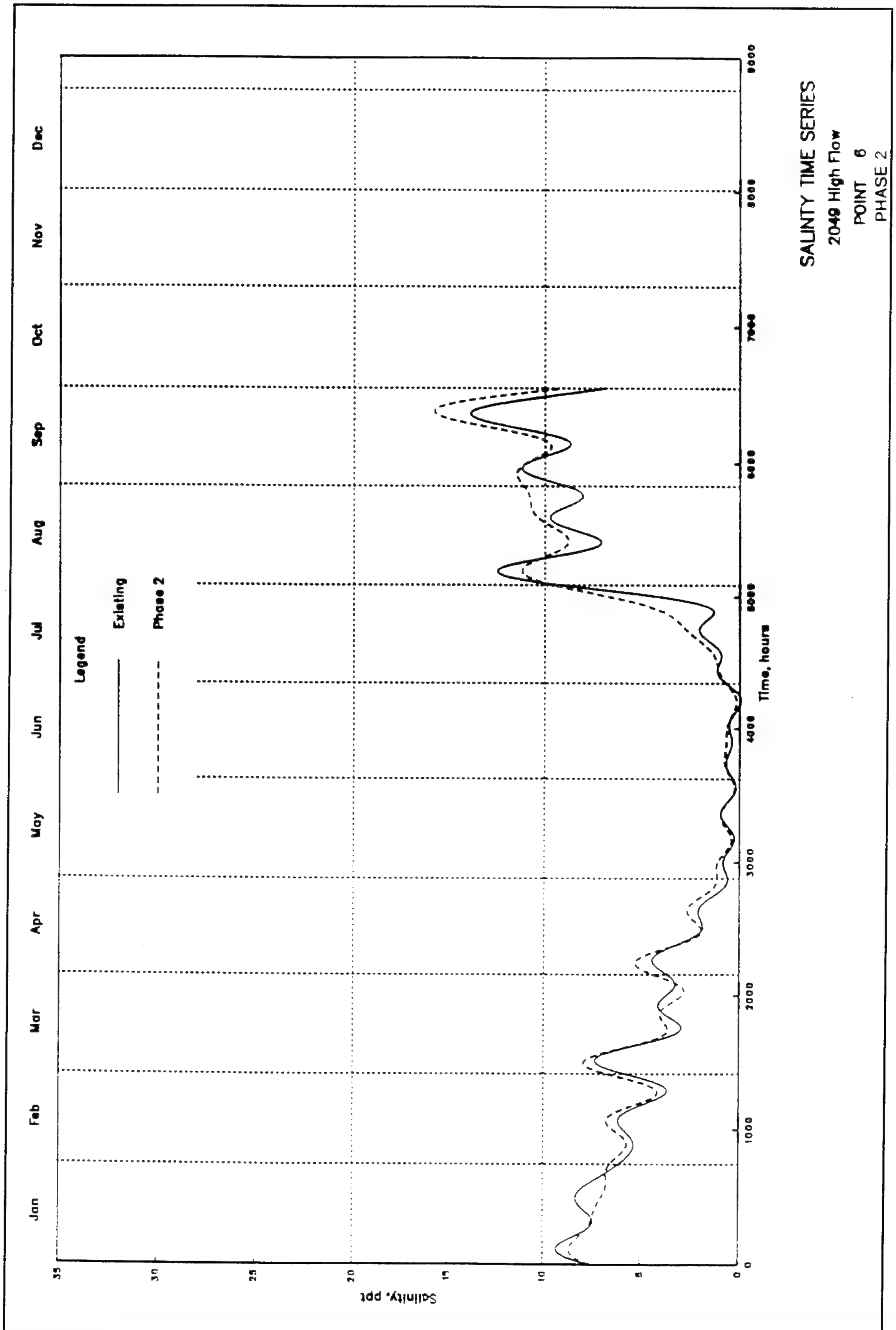

SALINTY TIME SERIES
2049 High Flow
POINT 5
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Plate 261


SALINTY TIME SERIES
2040 High Flow
POINT 6
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
0
5
10
15
20
25
30
35
0
1000
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7000
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Jan
Feb
Mar
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May
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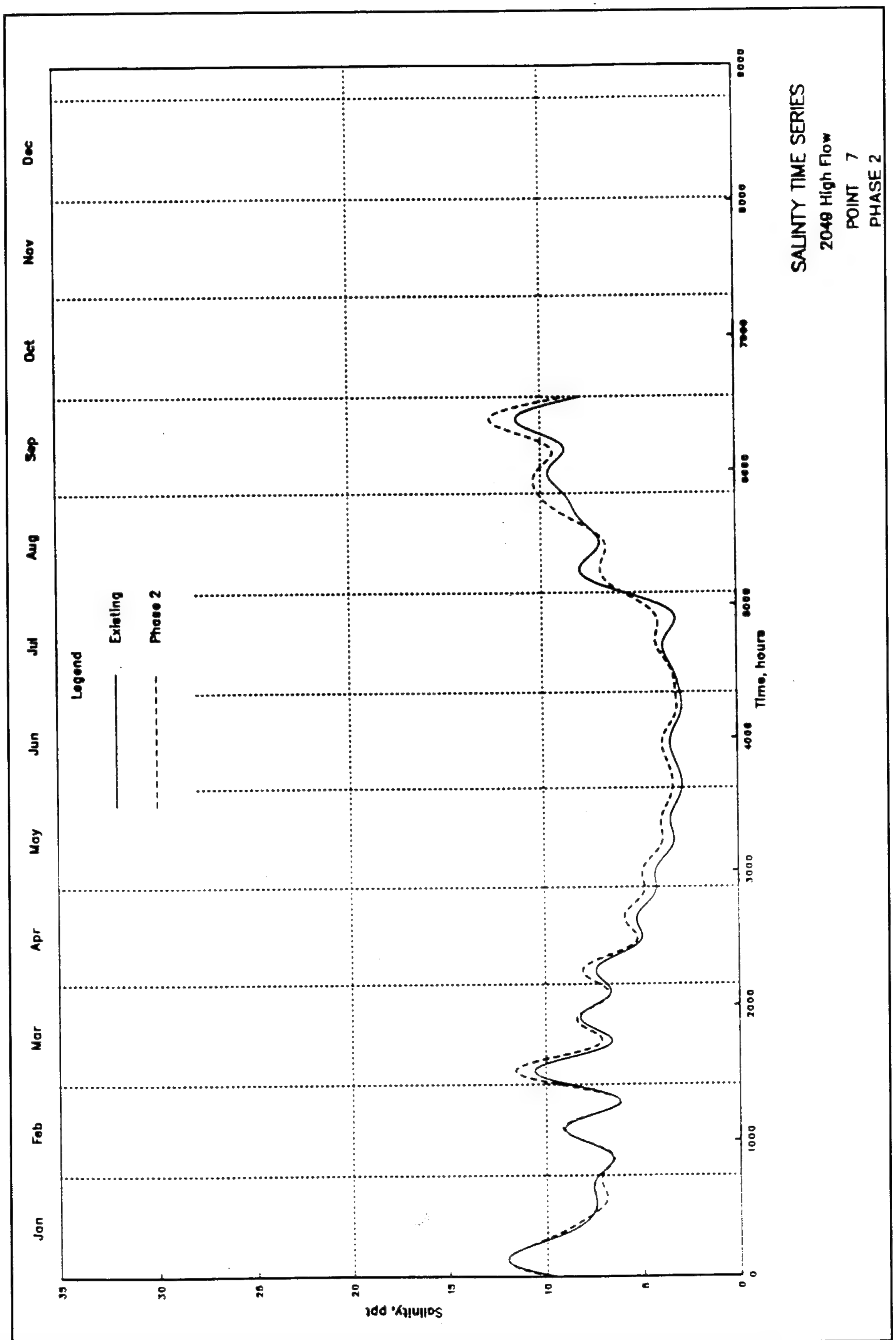
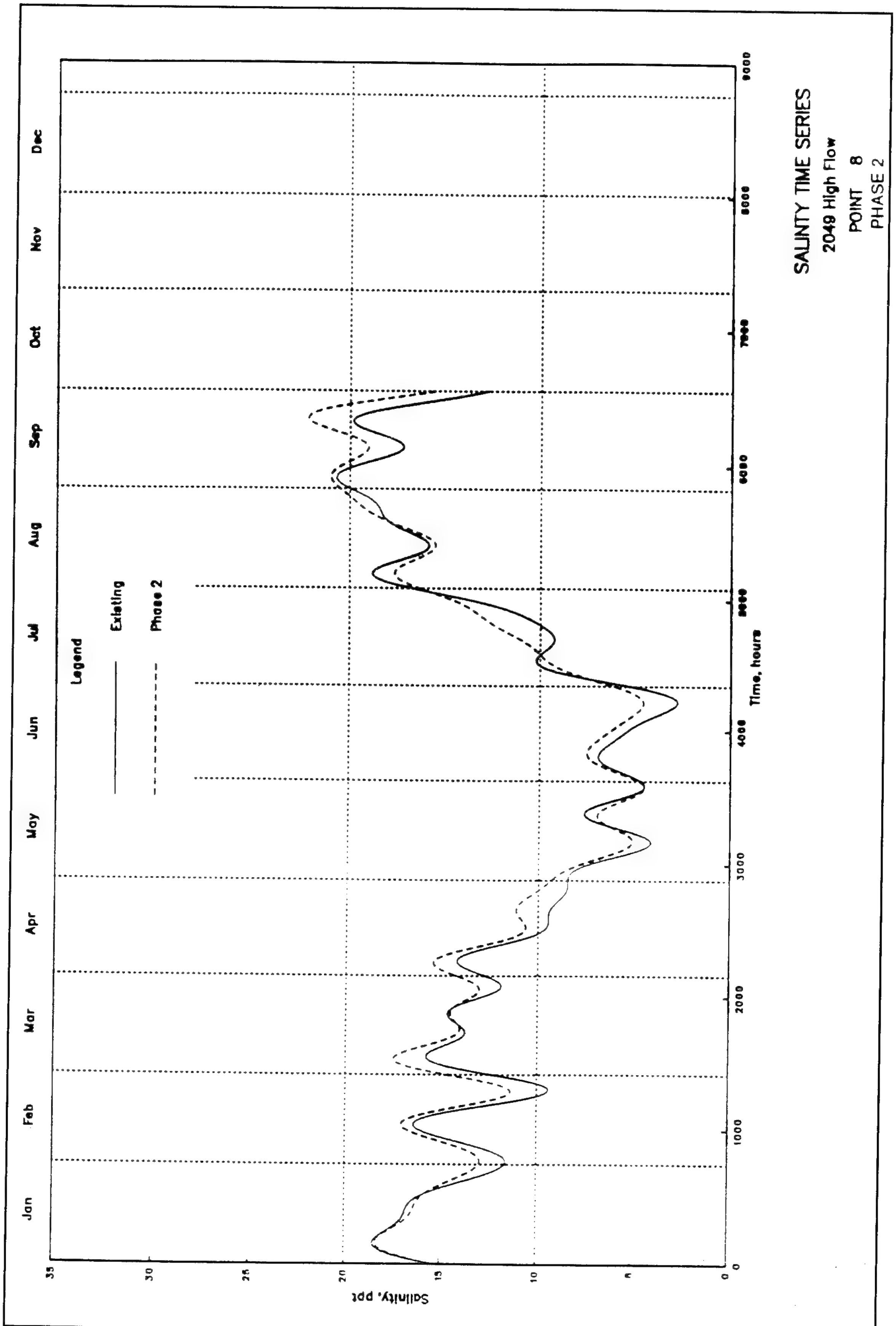
Aug
Sep
Oct
Nov
Dec

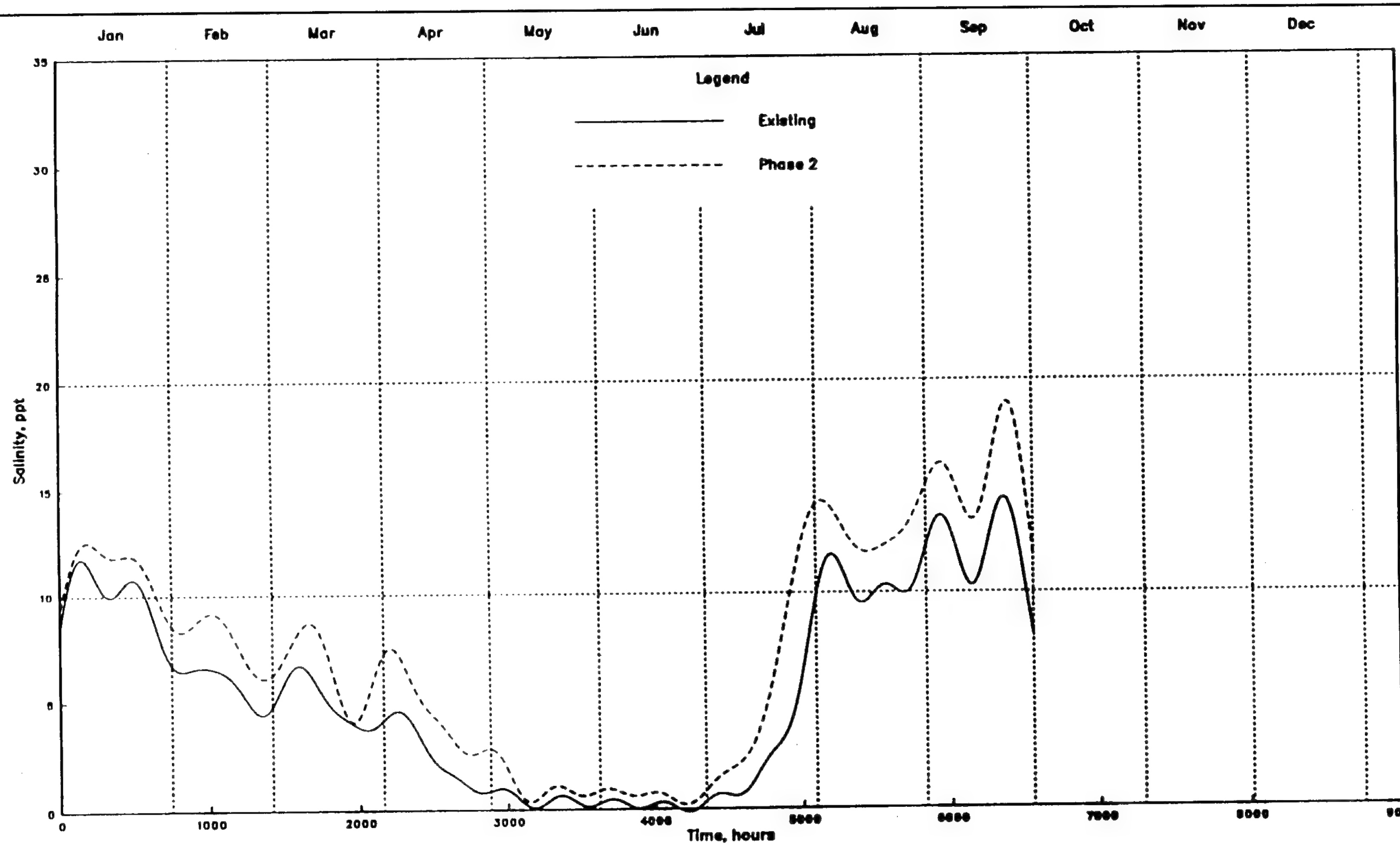


SALINTY TIME SERIES
2048 High Flow
POINT 7
PHASE 2



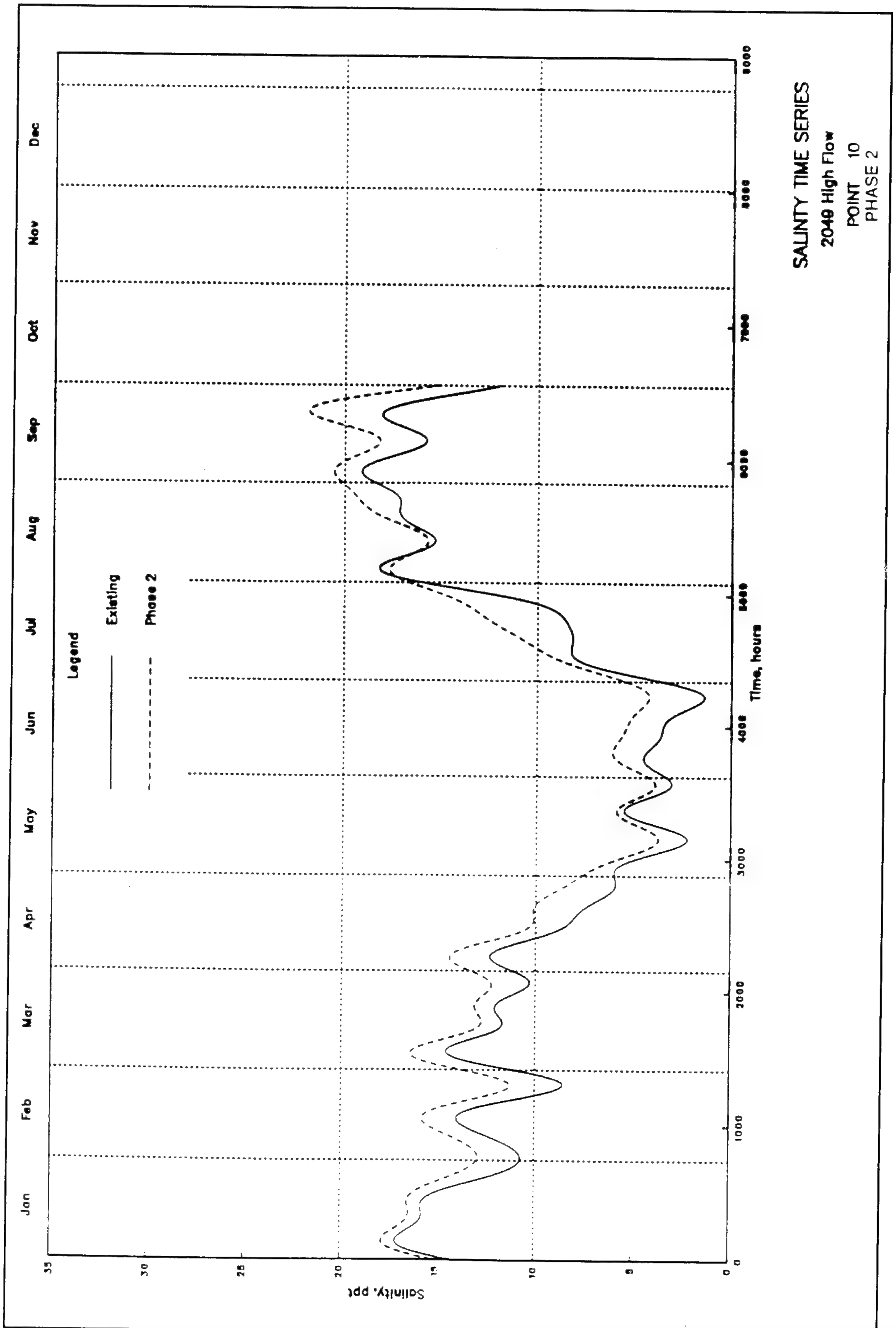
SALINTY TIME SERIES
2049 High Flow
POINT 8
PHASE 2
Legend
Existing
Phase 2
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Salinity, ppt
Time, hours
0
1000
2000
3000
4000
5
10
15
20
25
30
35

Plate 264



SALINTY TIME SERIES
2049 High Flow
POINT 9
PHASE 2

Plate 265


SALINTY TIME SERIES
2049 High Flow
POINT 10
PHASE 2
Legend
Existing
Phase 2
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Salinity, ppt
Time, hours
0
5
10
15
20
25
30
35
0
1000
2000
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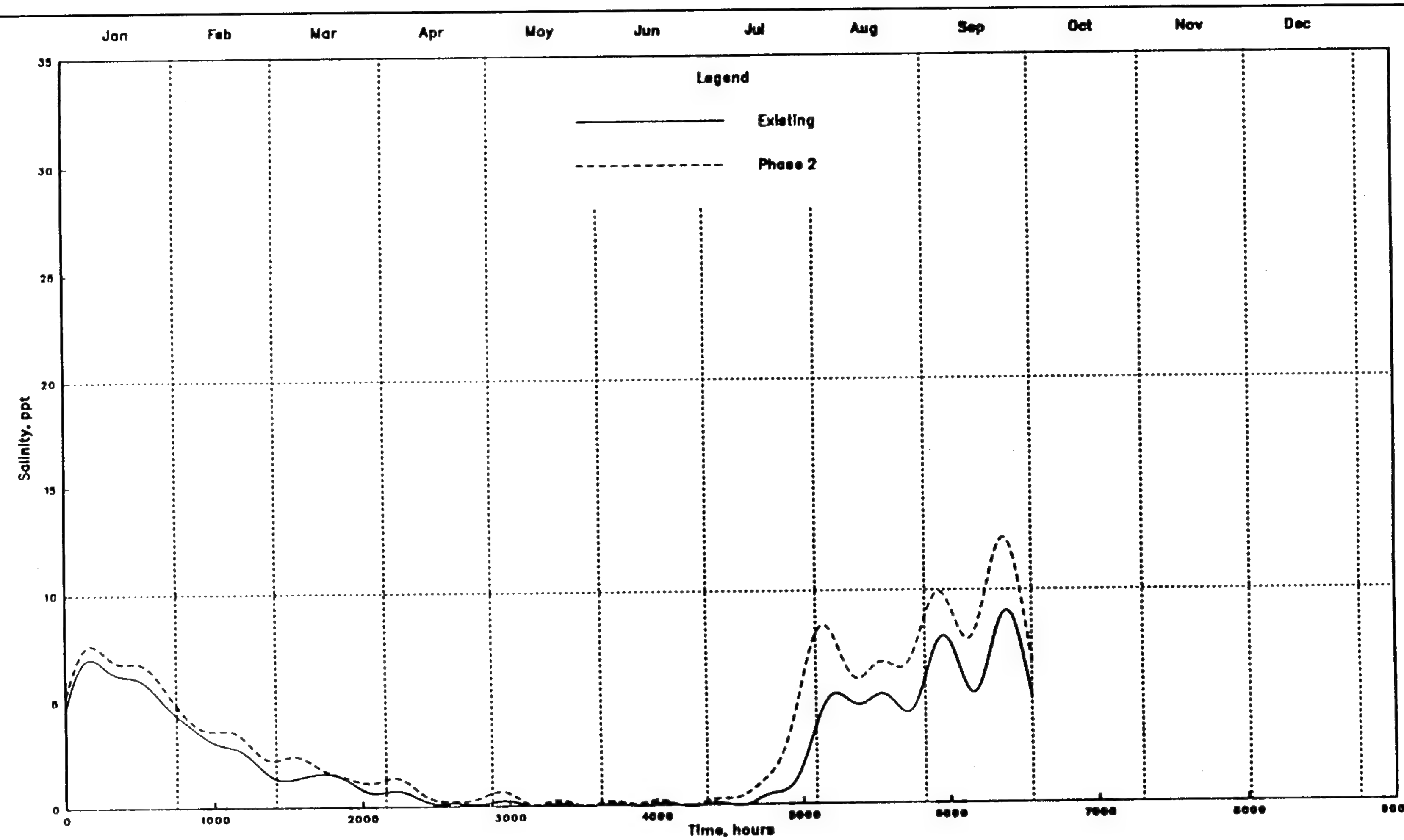
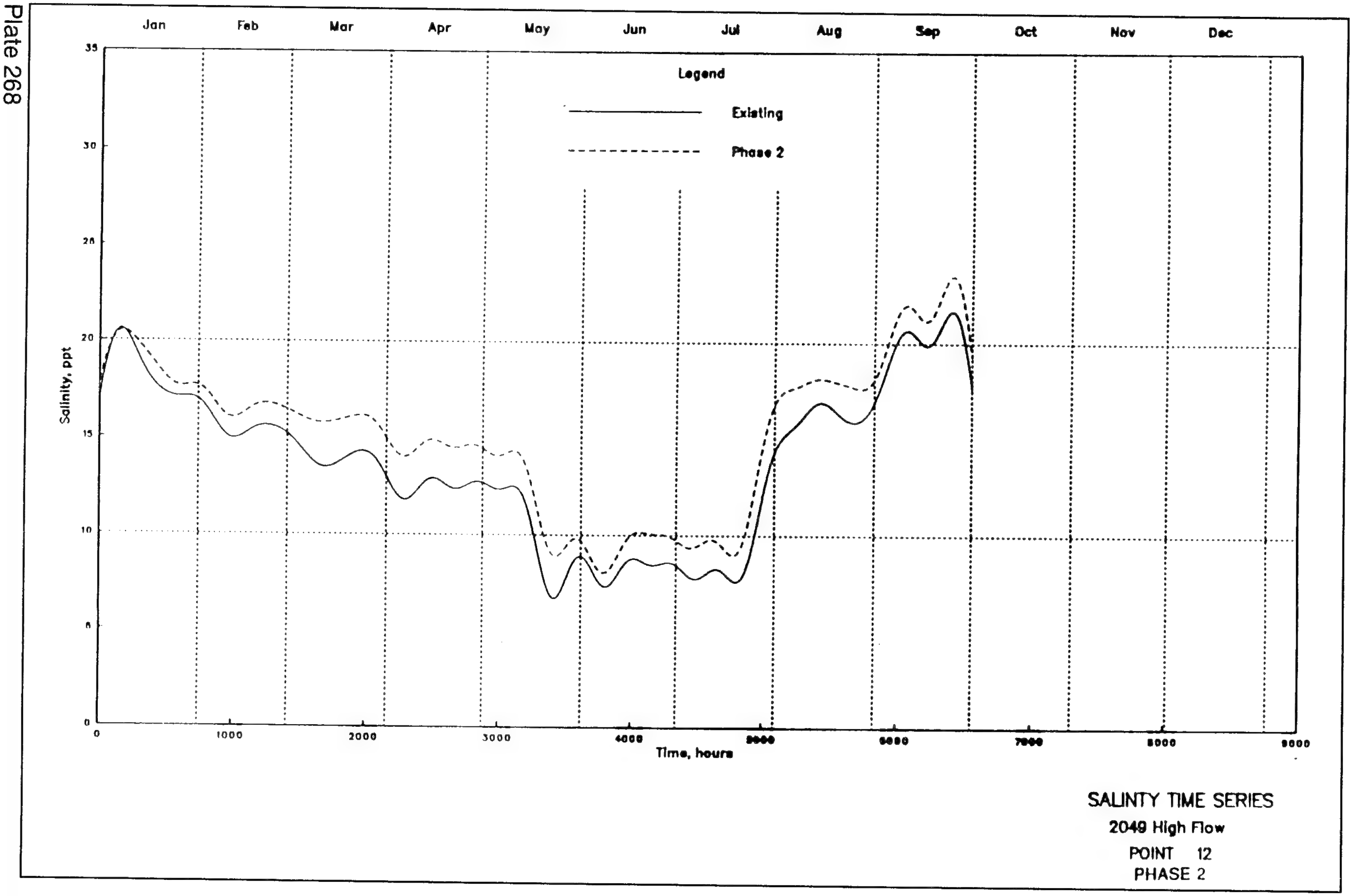


SALINTY TIME SERIES
2049 High Flow
POINT 11
PHASE 2


Jan
Feb
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Jun
Jul
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Oct
Nov
Dec
Legend
Existing
Phase 2
Salinity, ppt
35
30
25
20
15
10
5
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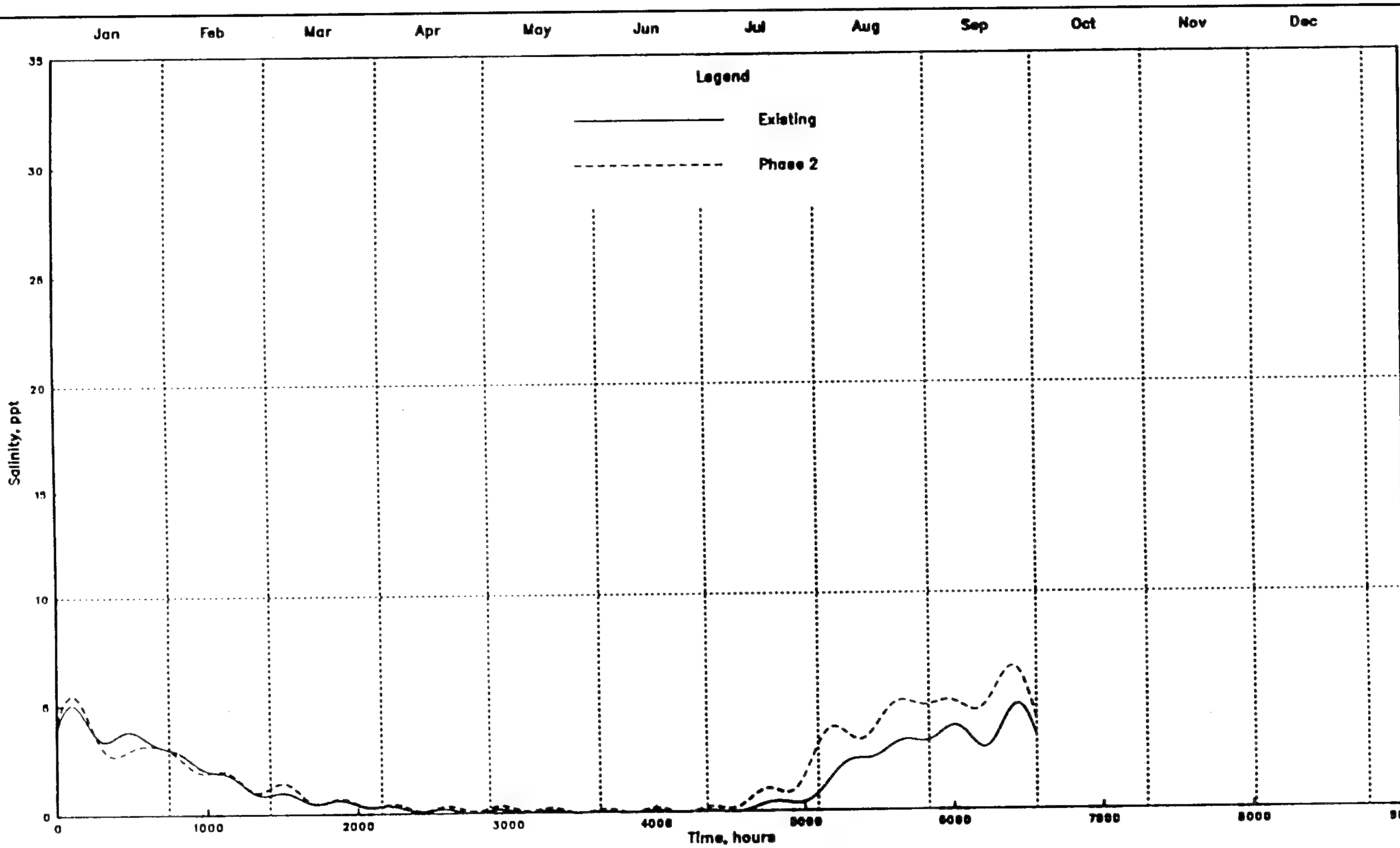
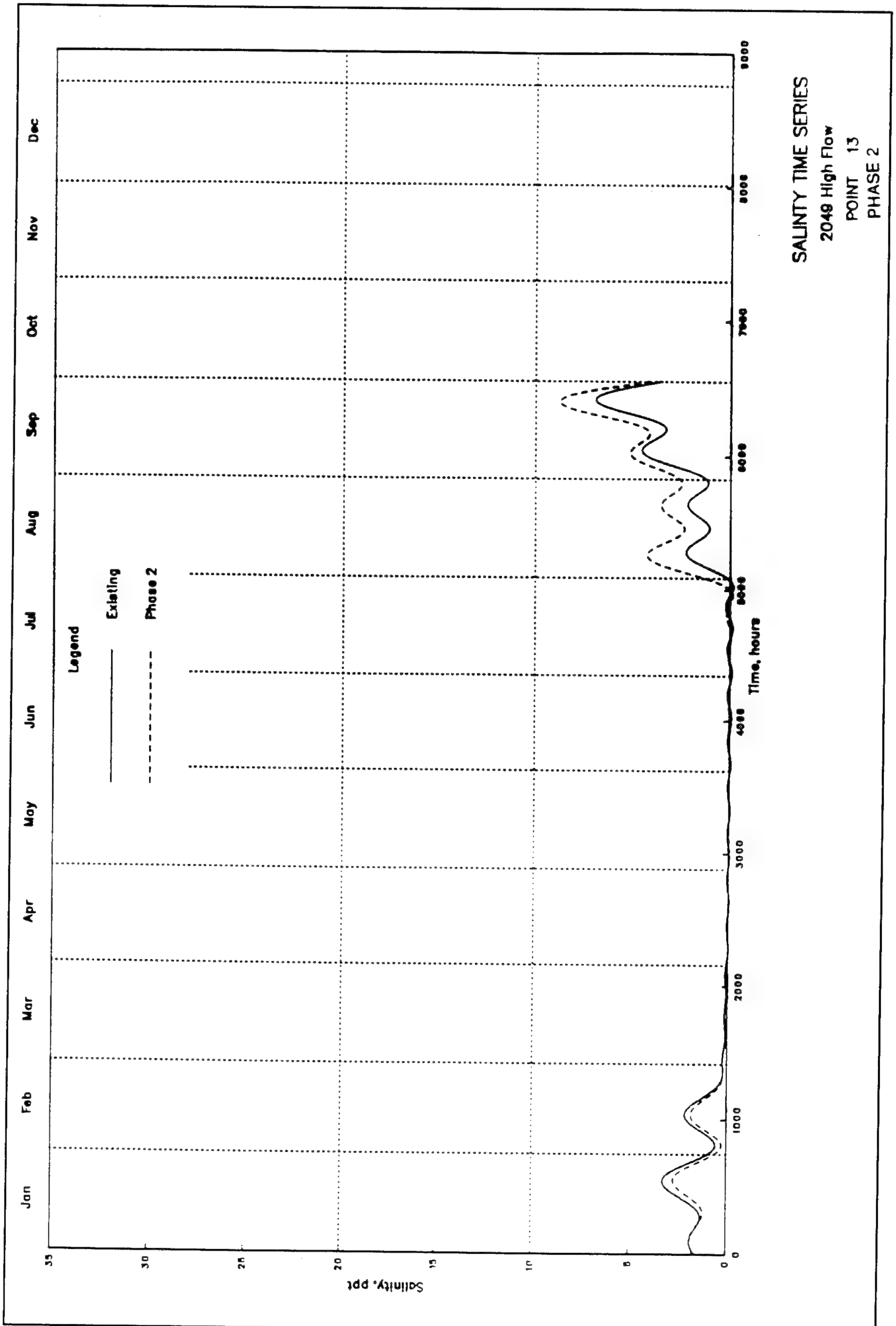
5000
6000
7000
8000
9000
Time, hours
SALINTY TIME SERIES
2049 High Flow
POINT 12
PHASE 2



SALINTY TIME SERIES
2049 High Flow
POINT 14
PHASE 2


SALINTY TIME SERIES
2049 High Flow
POINT 13
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
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Oct
Nov
Dec
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8000
9000
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15
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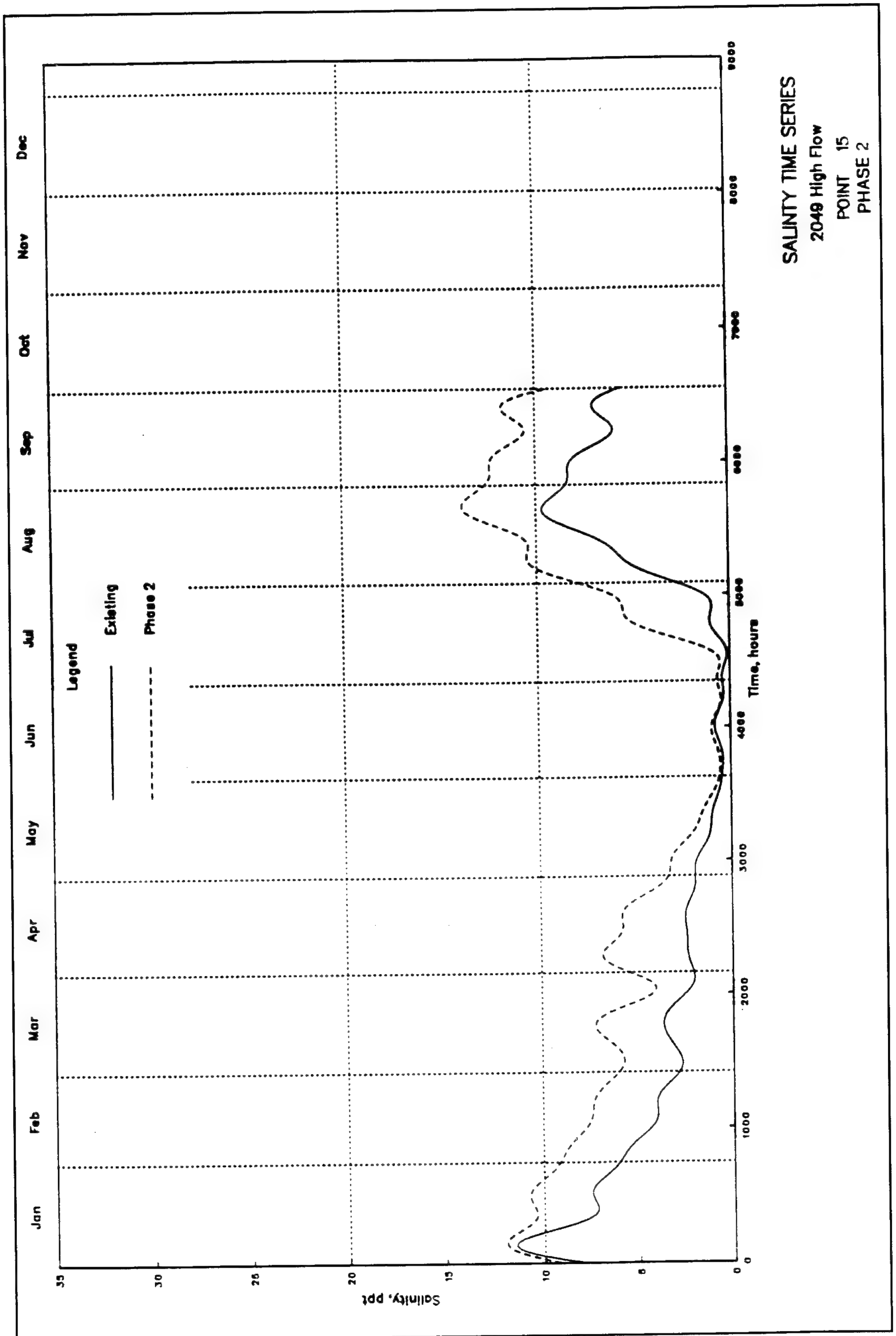
SALINITY TIME SERIES
2049 High Flow
POINT 15
PHASE 2
Legend
Existing
Phase 2
Salinity, ppt
Time, hours
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0
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5000
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7000
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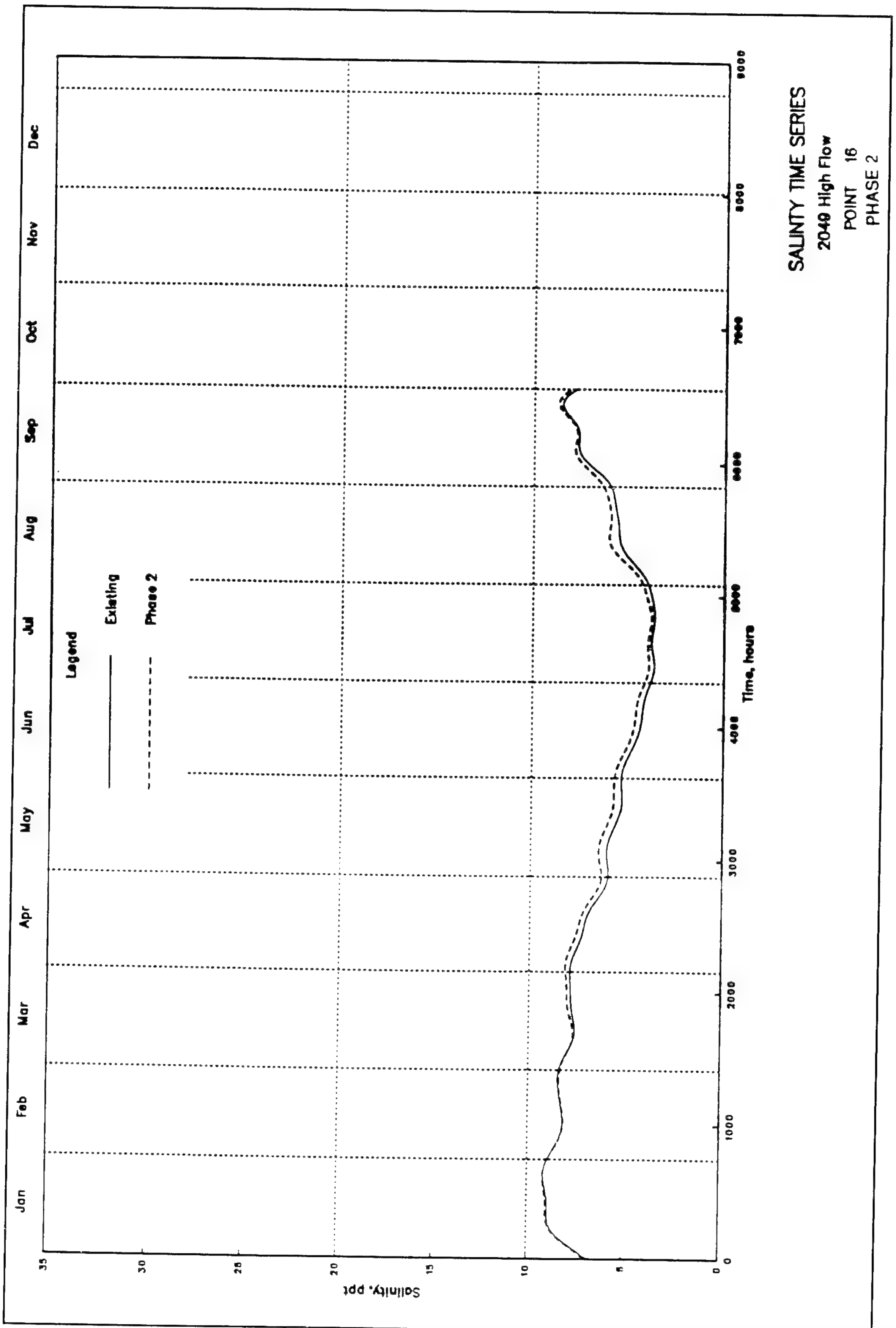
9000



SALINTY TIME SERIES
2049 High Flow
POINT 16
PHASE 2
Legend
Existing
Phase 2
Time, hours
Salinity, ppt
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0
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2000
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4000
5000
6000
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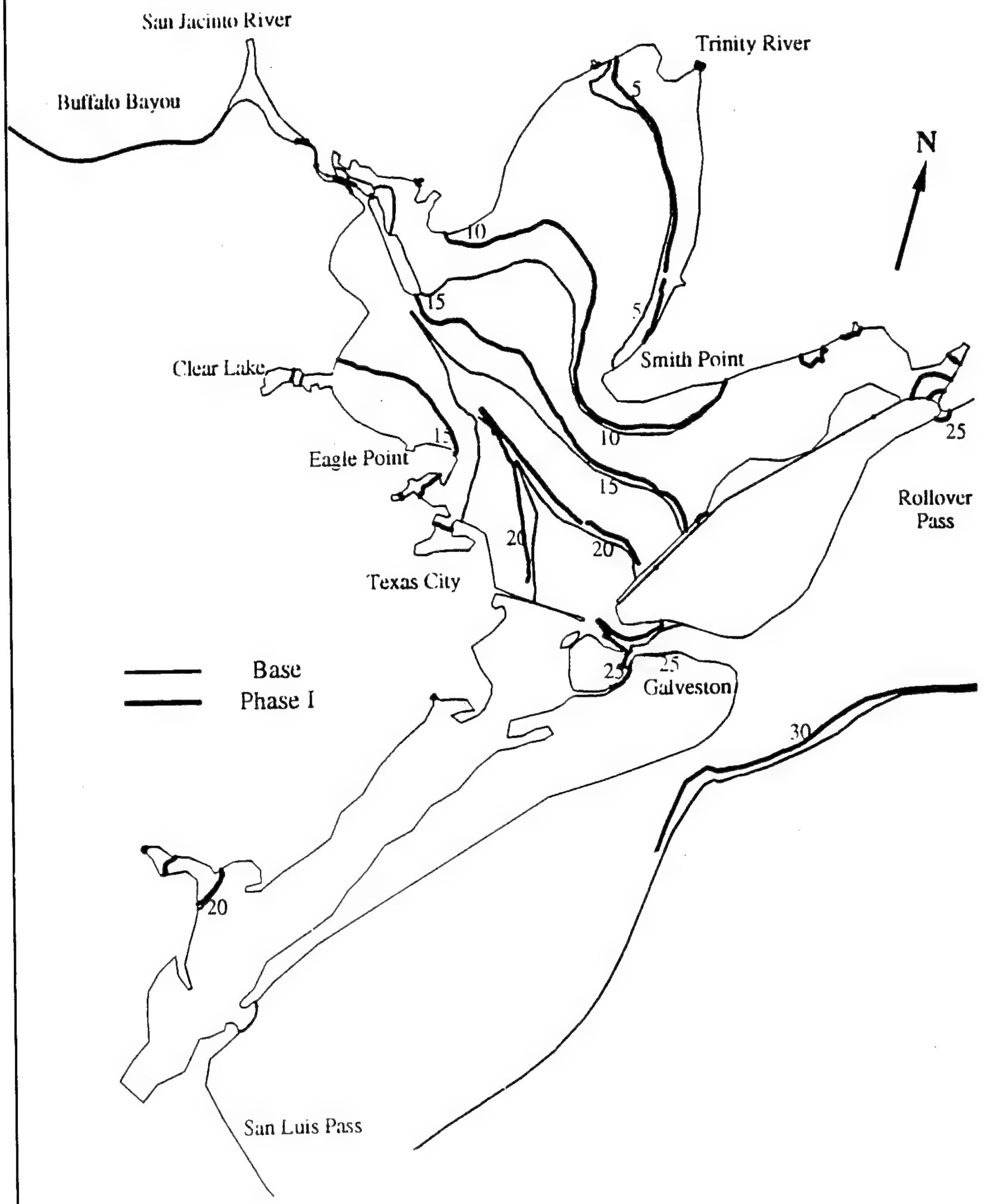
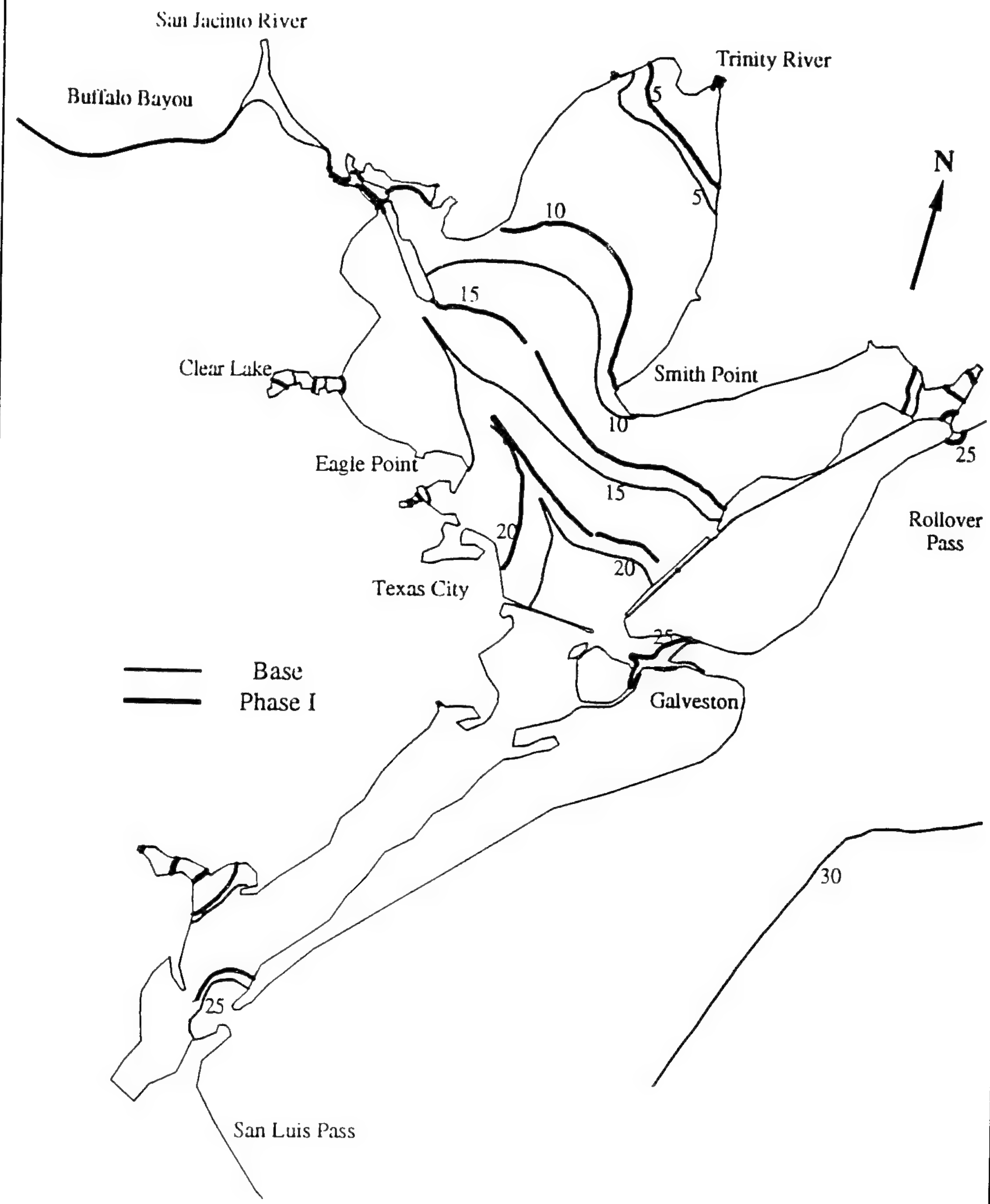
8000
9000
0
5
10
15
20
25
30
35

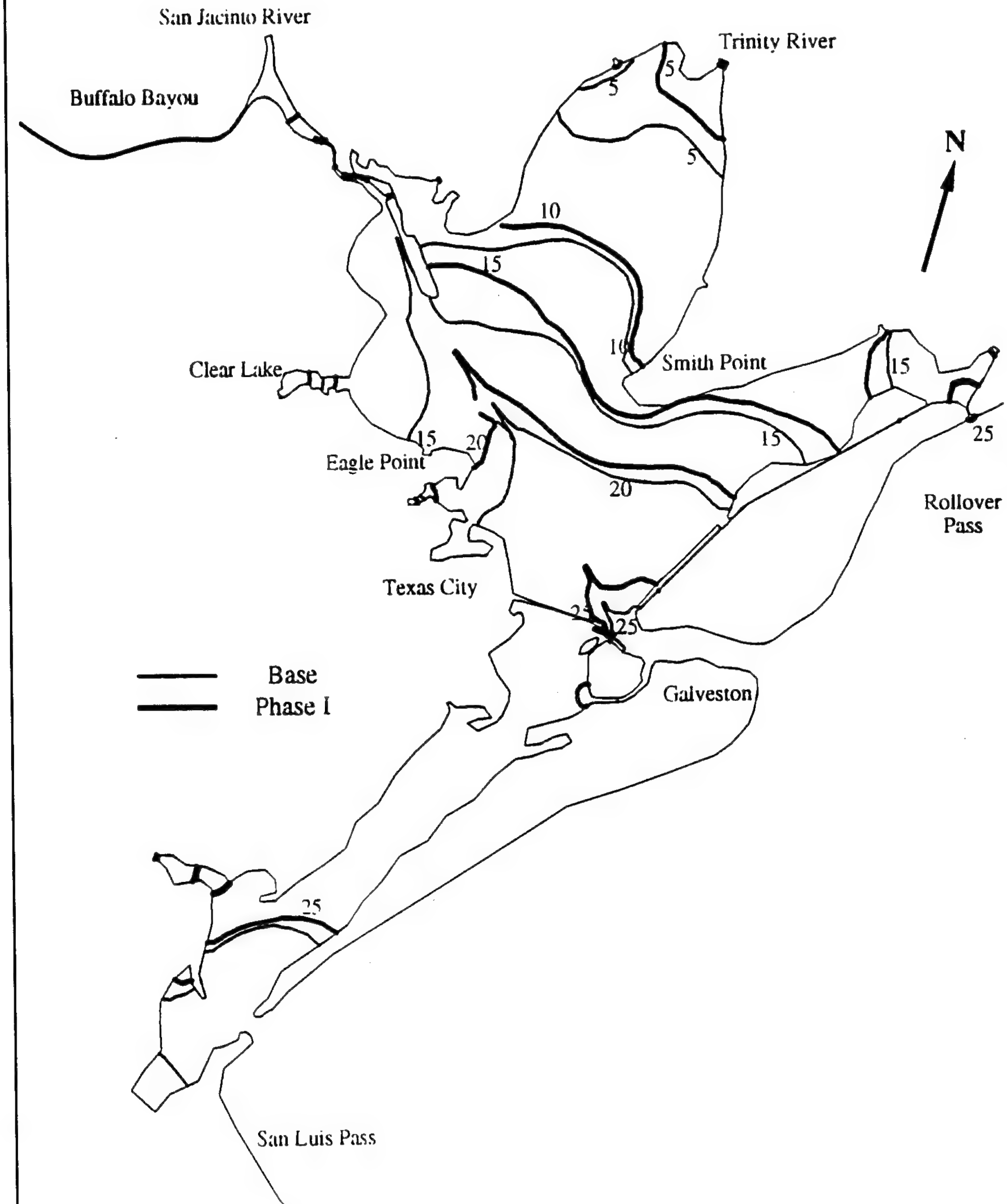
Plate 272



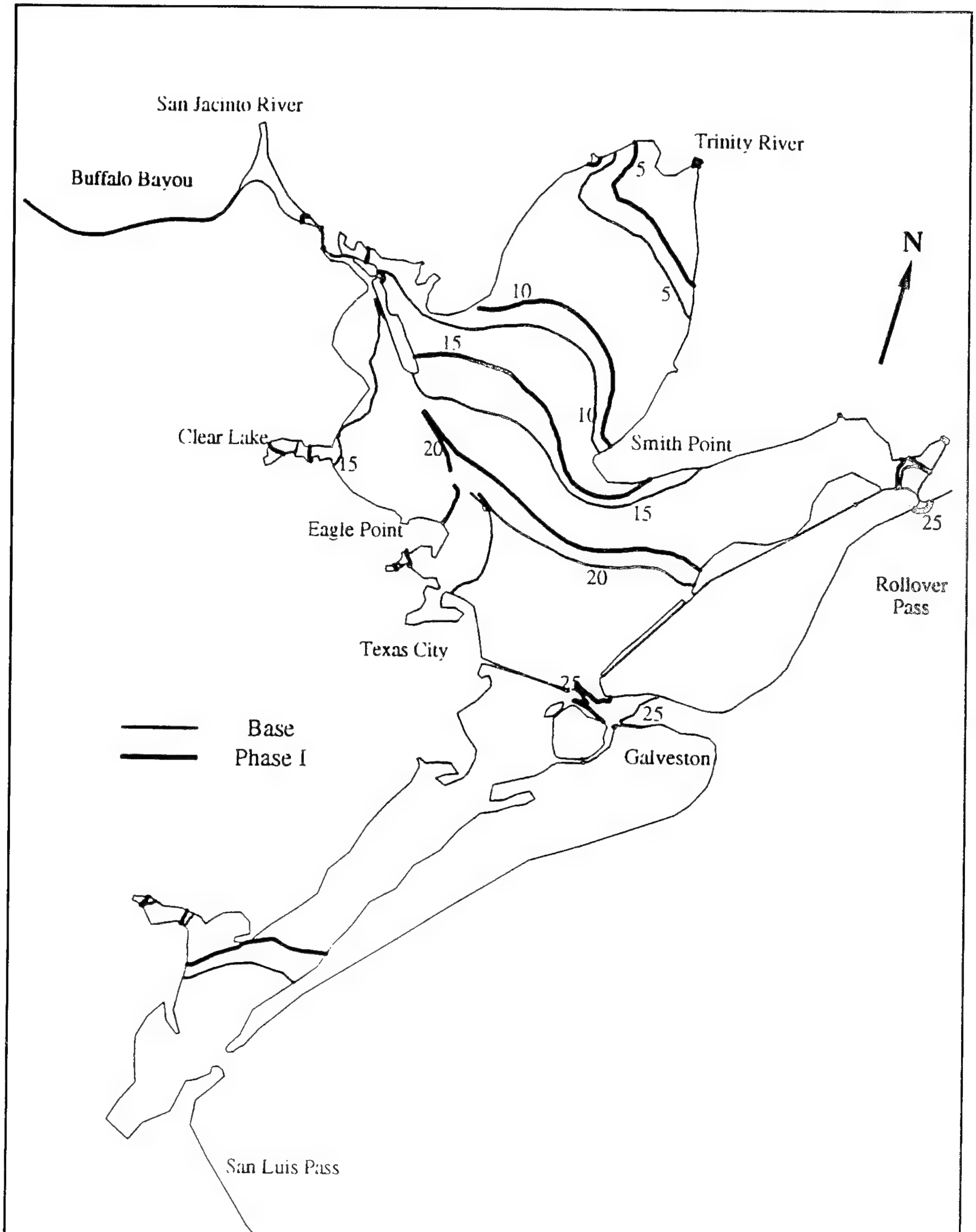
SALINITY CONTOURS, PPT
JANUARY 1990, PHASE I
LOW FLOW, BOTTOM



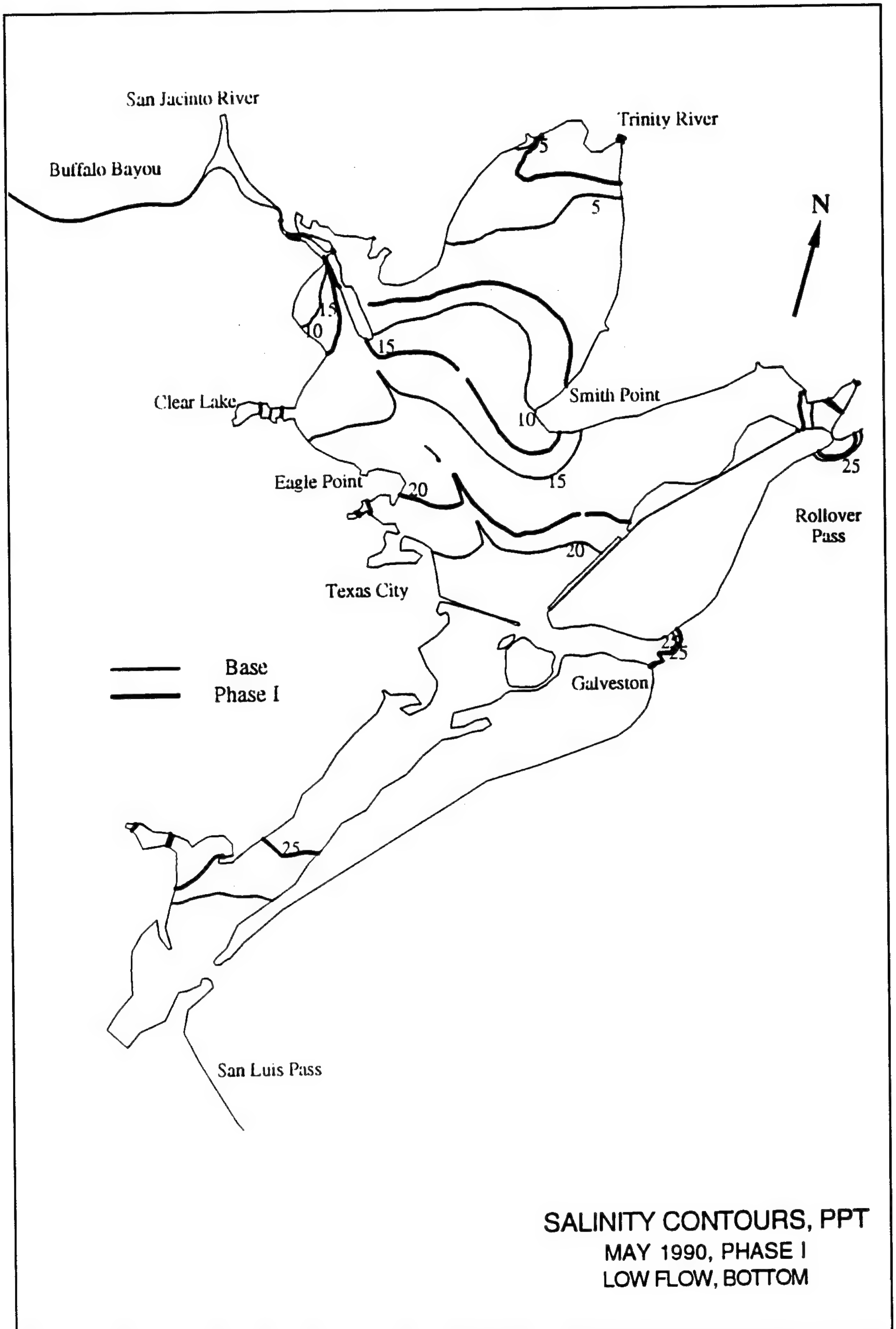
SALINITY CONTOURS, PPT
FEBRUARY 1990, PHASE I
LOW FLOW, BOTTOM

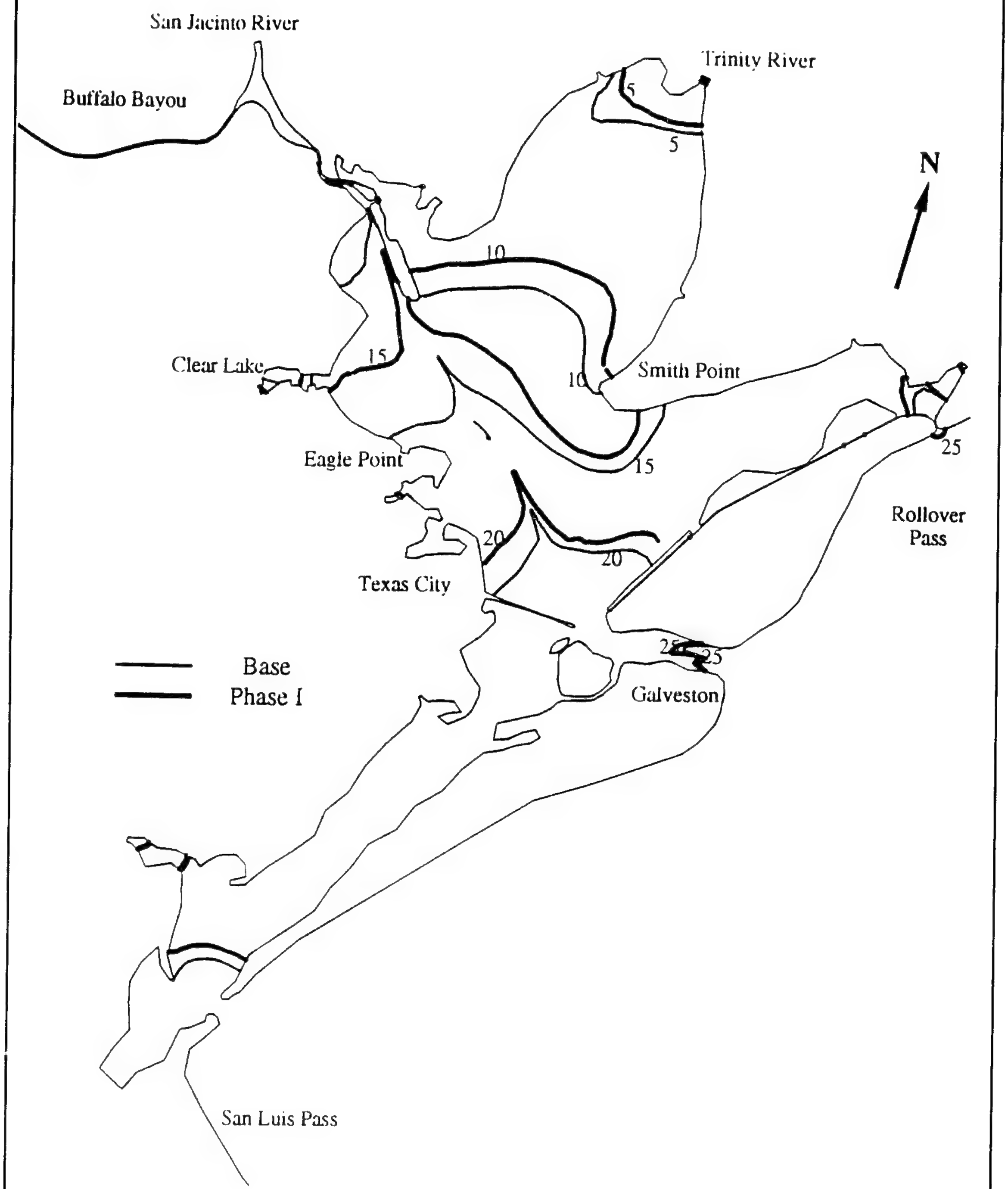


SALINITY CONTOURS, PPT
MARCH 1990, PHASE I
LOW FLOW, BOTTOM

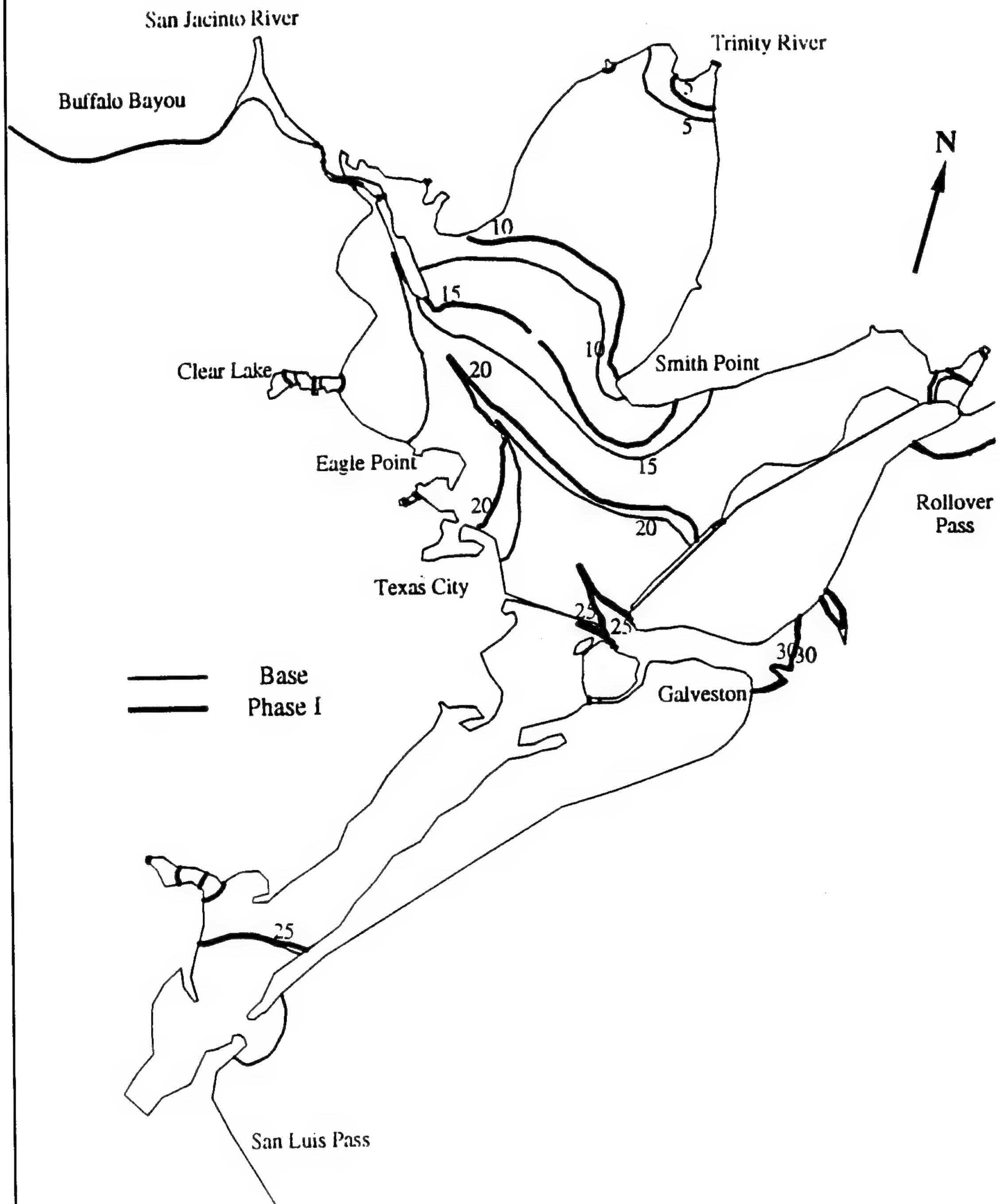


SALINITY CONTOURS, PPT
APRIL 1990, PHASE I
LOW FLOW, BOTTOM


San Jacinto River
Trinity River
Buffalo Bayou
N
5
5
15
10
15
Clear Lake
Smith Point
10
Eagle Point
20
15
25
Rollover
Pass
20
Texas City
Base
Phase I
25
Galveston
25
San Luis Pass
SALINITY CONTOURS, PPT
MAY 1990, PHASE I
LOW FLOW, BOTTOM



SALINITY CONTOURS, PPT
JUNE 1990, PHASE I
LOW FLOW, BOTTOM



SALINITY CONTOURS, PPT
JULY 1990, PHASE I
LOW FLOW, BOTTOM

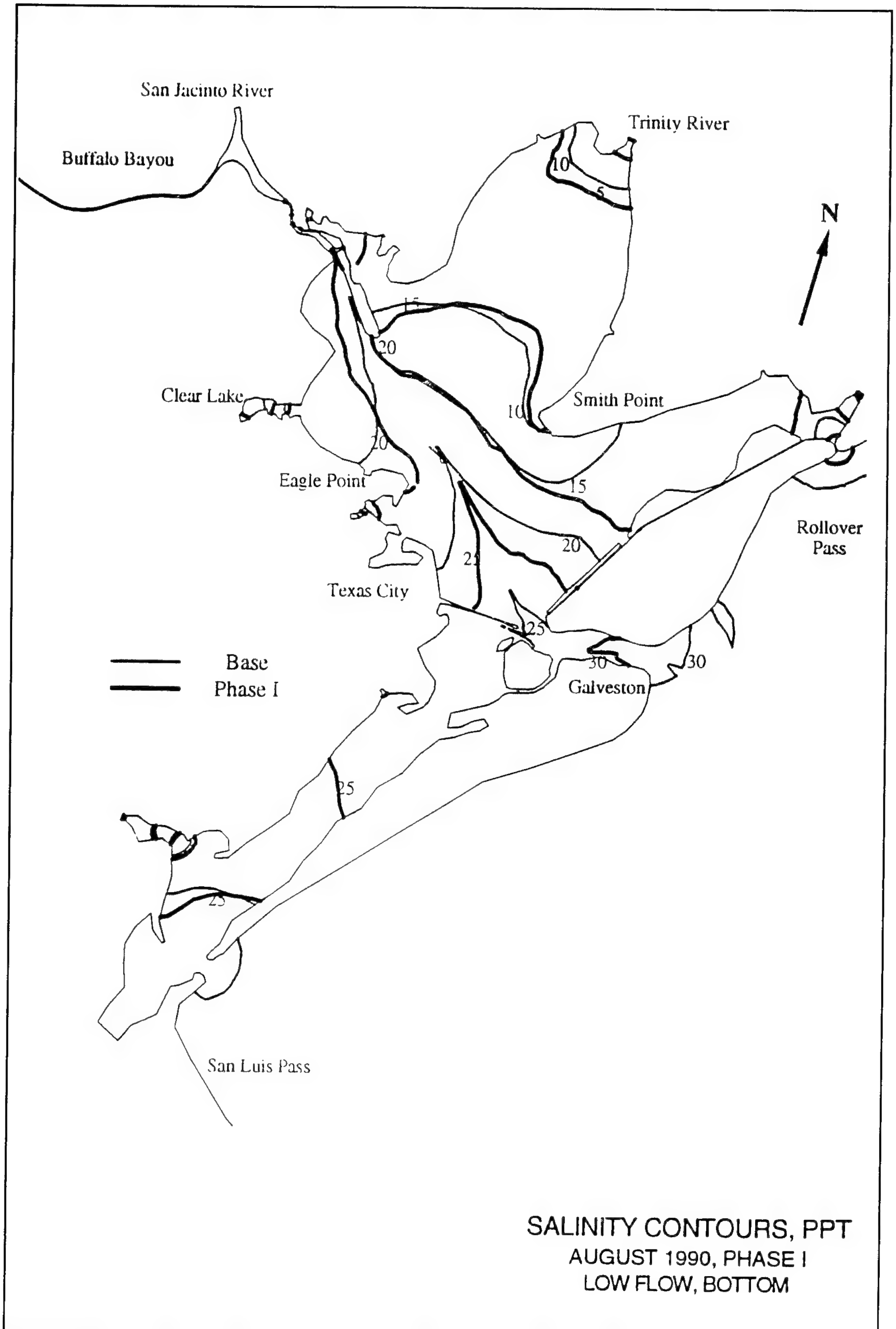
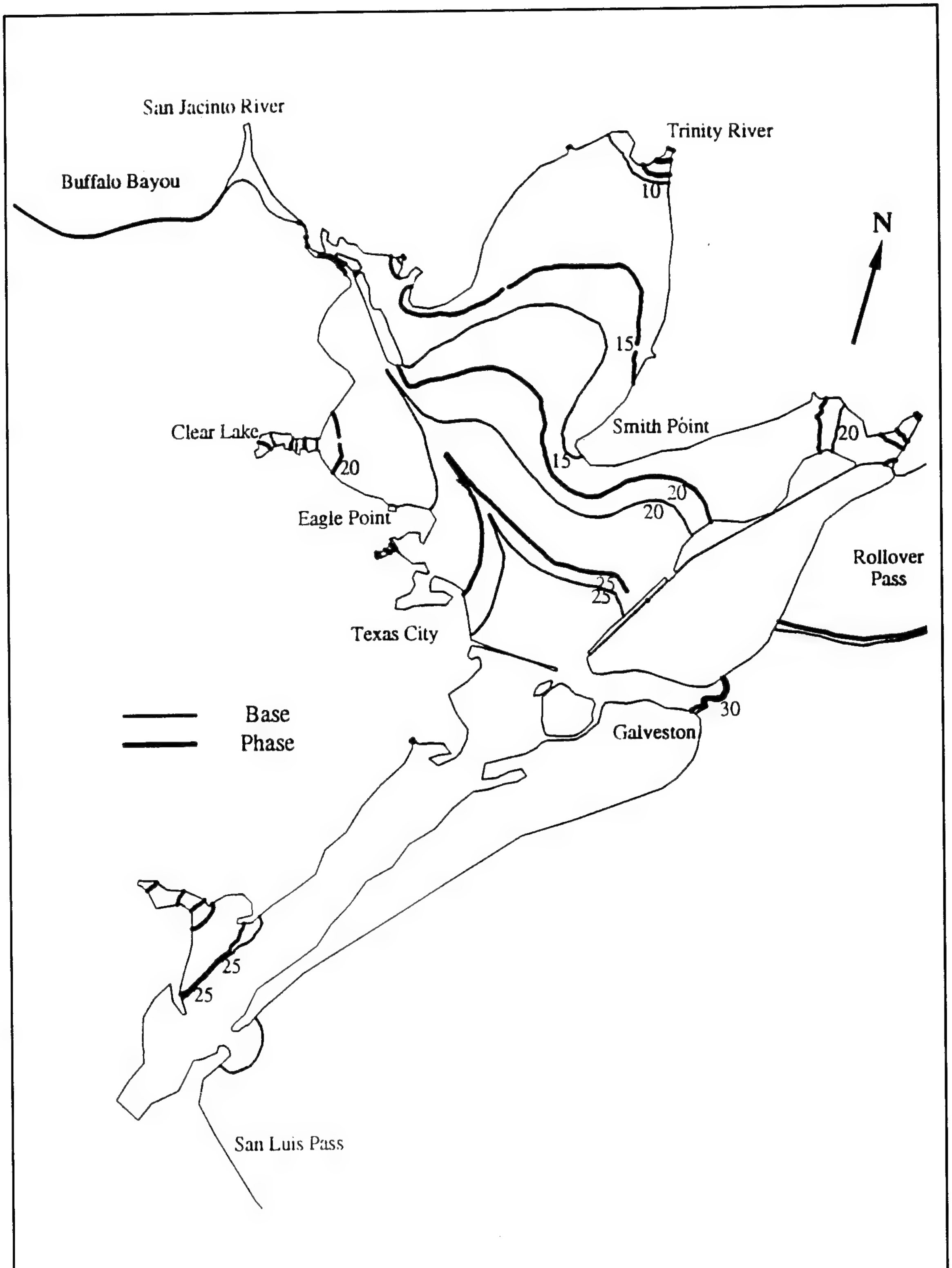

San Jacinto River
Buffalo Bayou
Trinity River
N
10
5
15
20
10
Smith Point
Clear Lake
20
Eagle Point
15
20
21
Texas City
25
Rollover
Pass
Base
Phase I
30
30
Galveston
25
25
San Luis Pass
SALINITY CONTOURS, PPT
AUGUST 1990, PHASE I
LOW FLOW, BOTTOM

Plate 280


San Jacinto River
Buffalo Bayou
Trinity River
10
N
15
Clear Lake
20
Smith Point
15
20
20
20
Eagle Point
Rollover
Pass
25
25
Texas City
Base
Phase
30
Galveston
25
25
San Luis Pass
SALINITY CONTOURS, PPT
SEPTEMBER 1990, PHASE I
LOW FLOW, BOTTOM

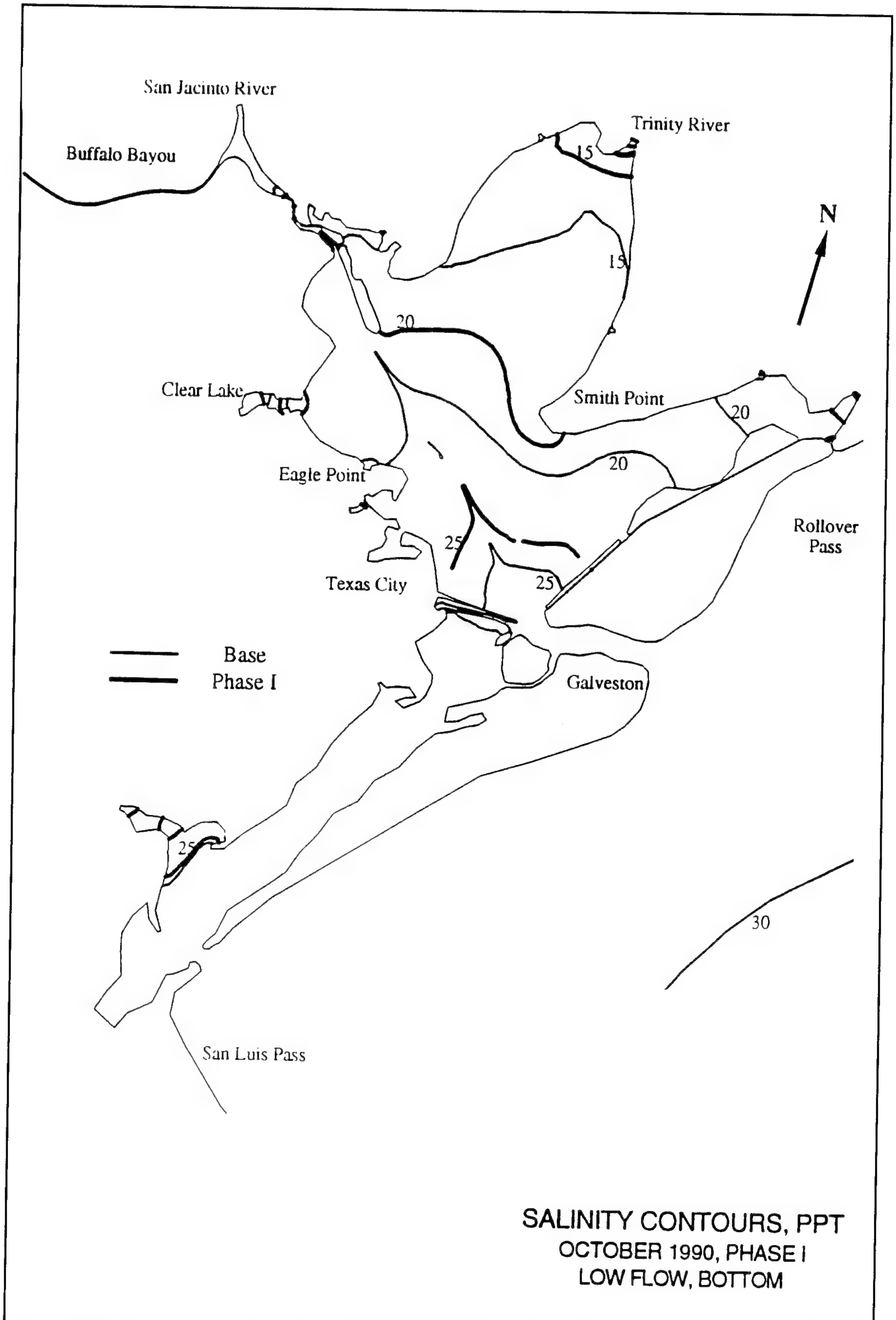
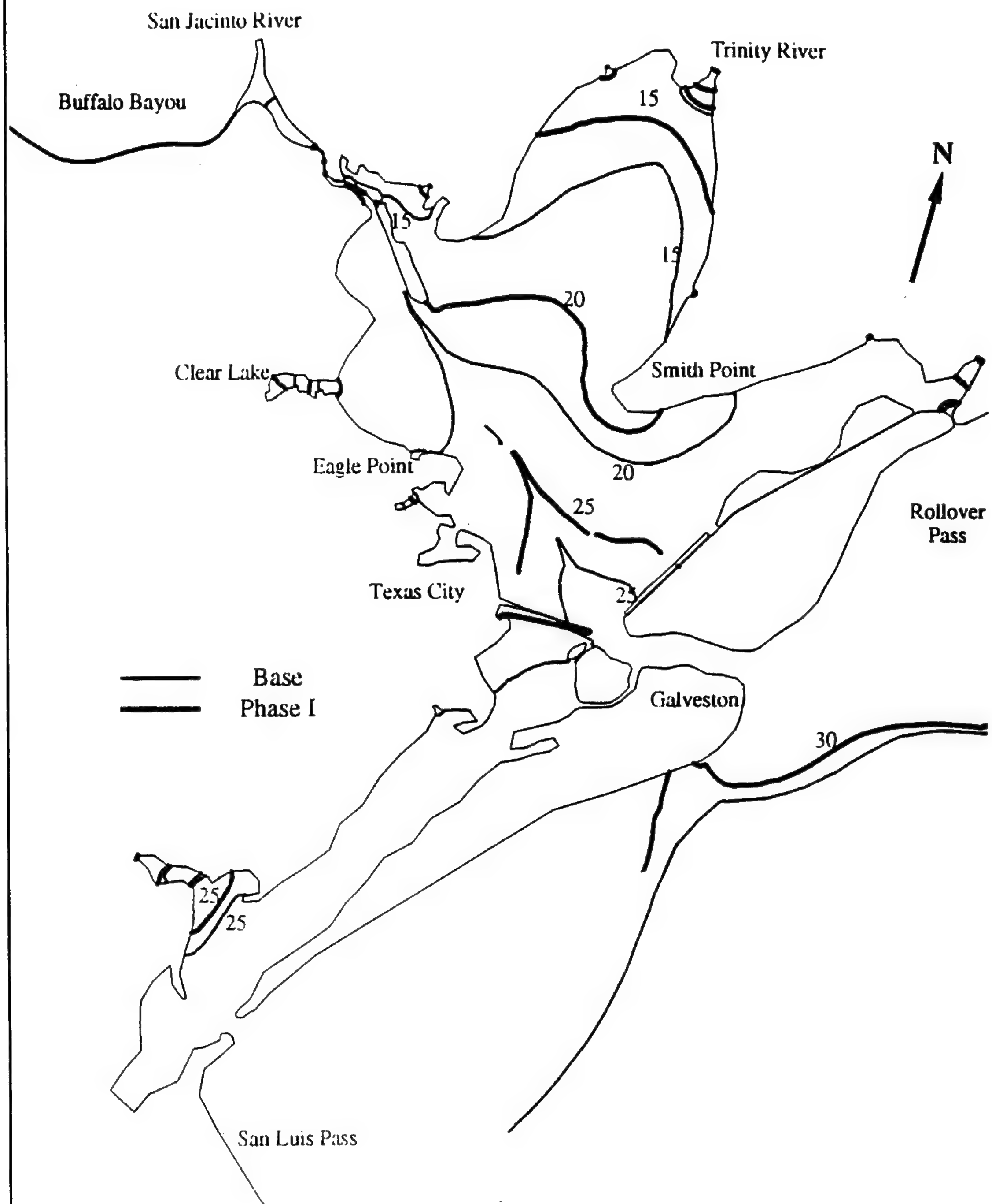
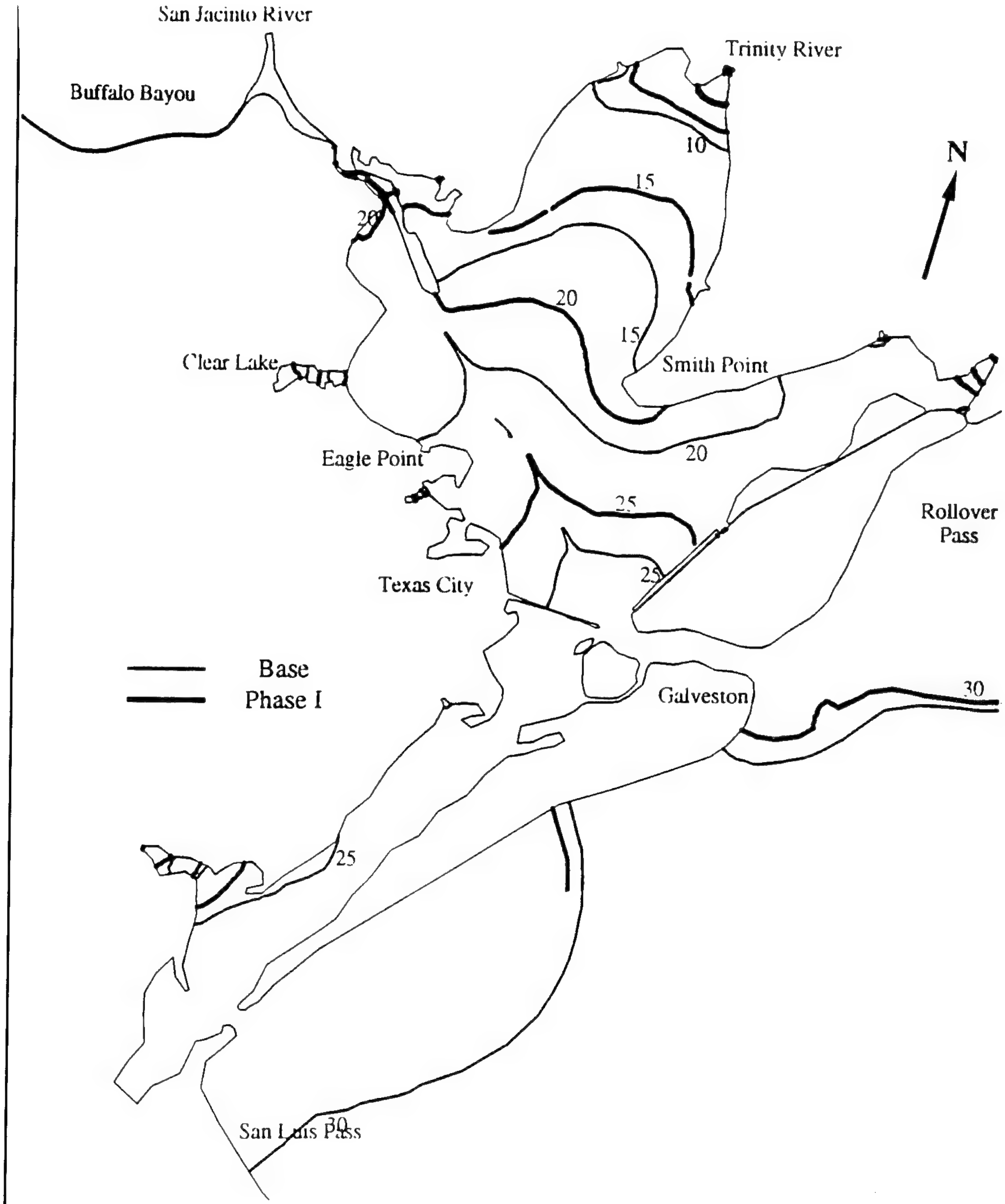

San Jacinto River
Buffalo Bayou
Trinity River
15
15
N
20
Clear Lake
Smith Point
20
Eagle Point
20
Rollover
Pass
25
25
Texas City
Base
Phase I
Galveston
25
30
San Luis Pass
SALINITY CONTOURS, PPT
OCTOBER 1990, PHASE I
LOW FLOW, BOTTOM

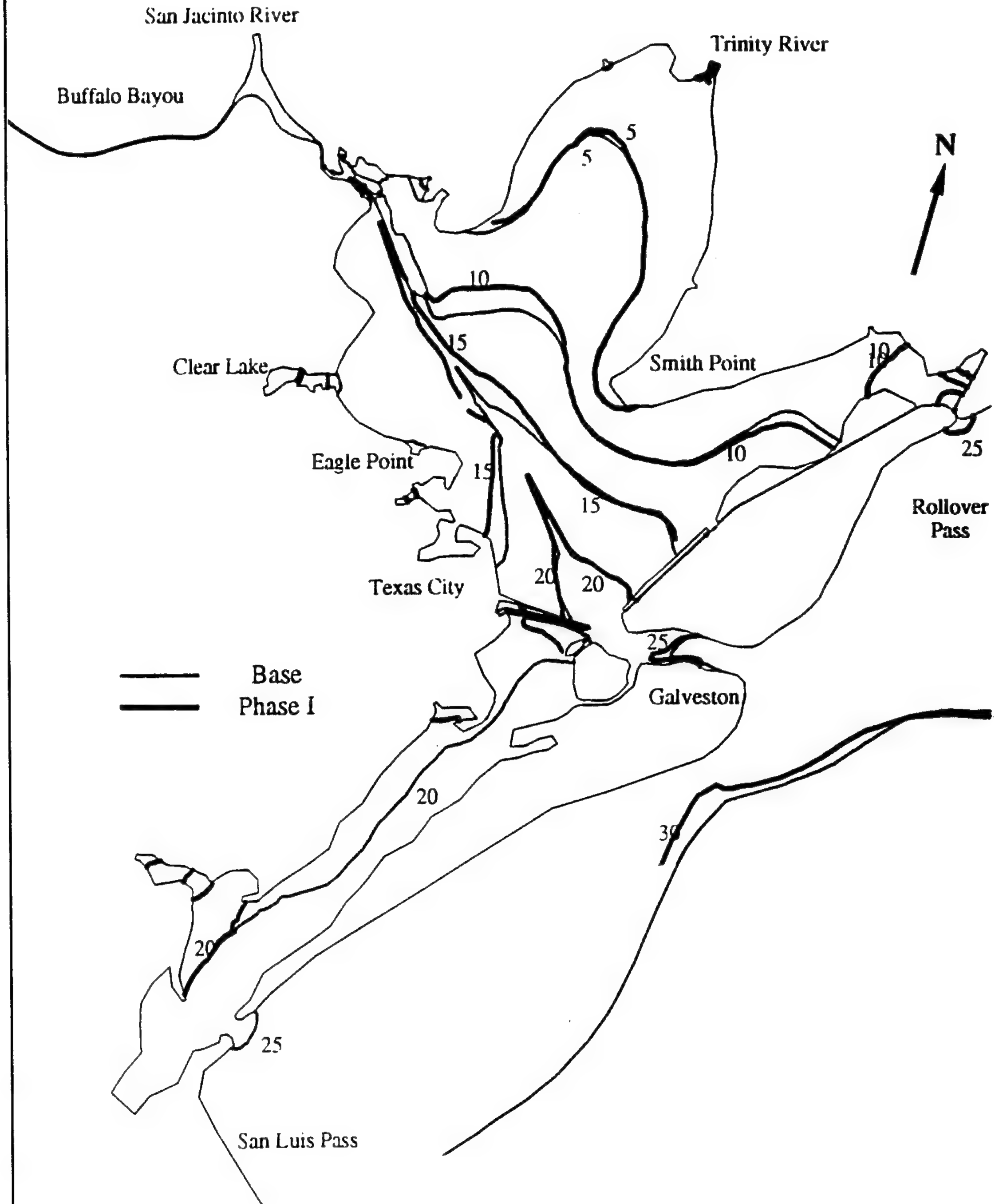
Plate 282



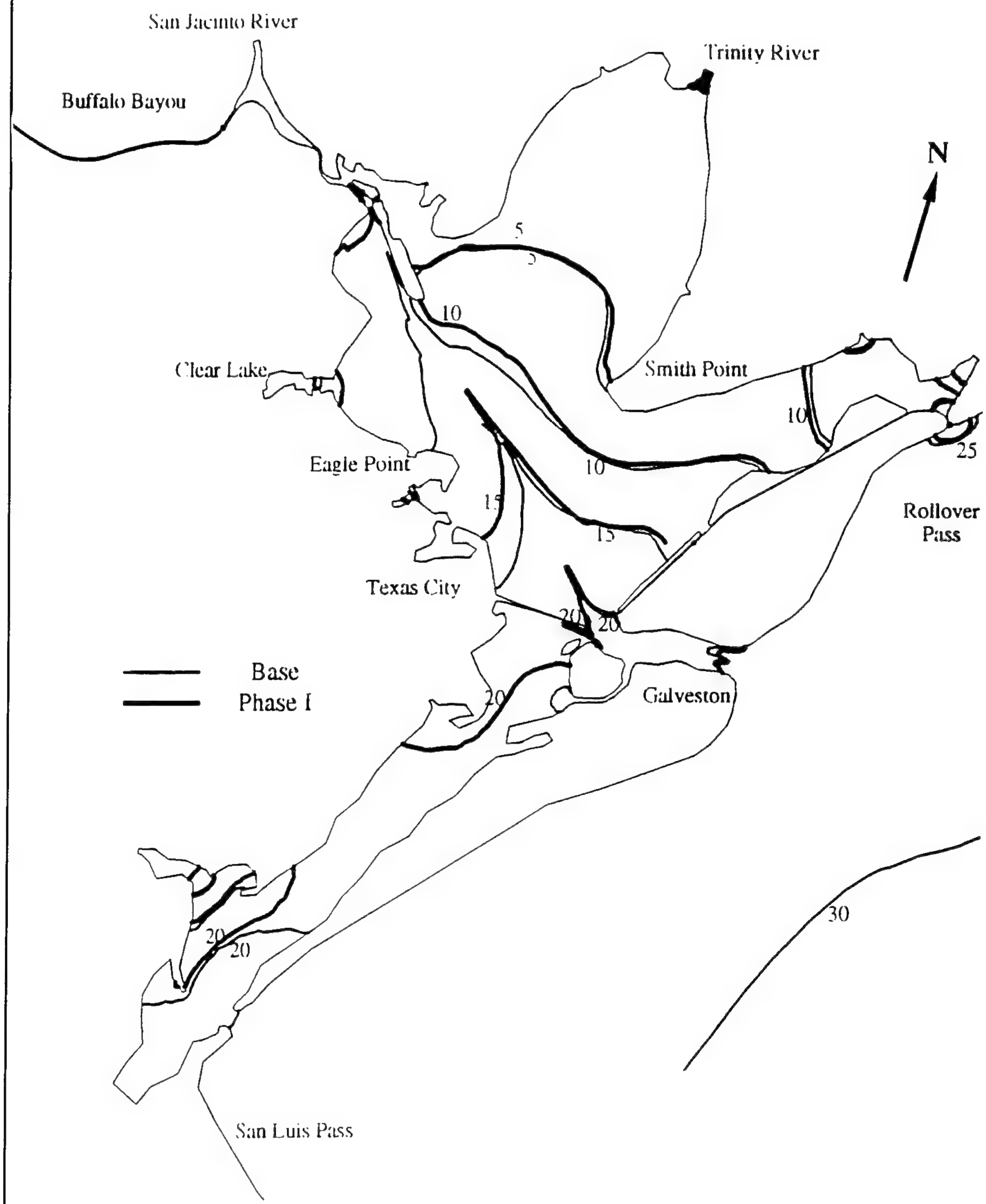
SALINITY CONTOURS, PPT
NOVEMBER 1990, PHASE I
LOW FLOW, BOTTOM



SALINITY CONTOURS, PPT
DECEMBER 1990, PHASE I
LOW FLOW, BOTTOM

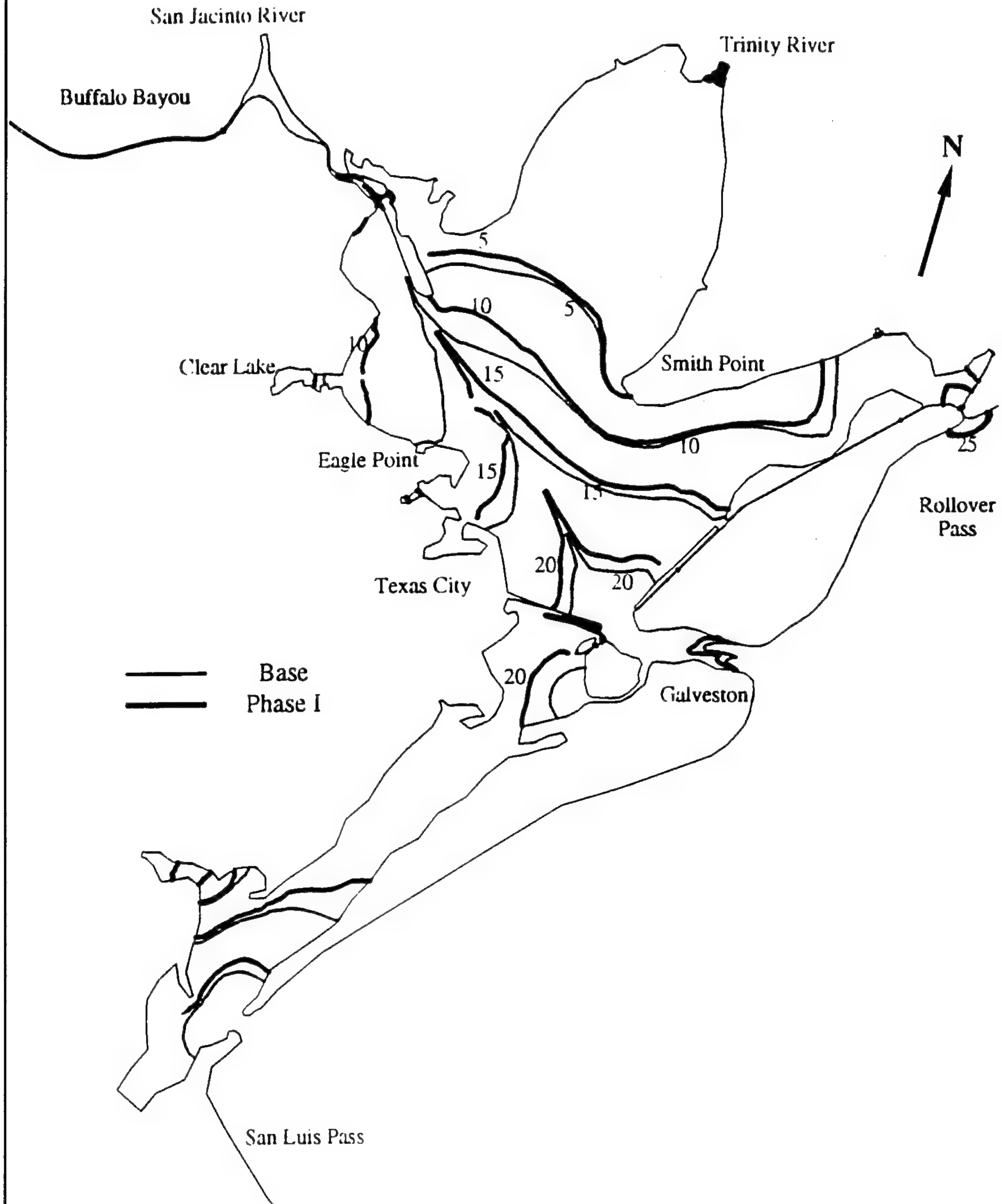


SALINITY CONTOURS, PPT
JANUARY 1990, PHASE I
MEDIUM FLOW, BOTTOM

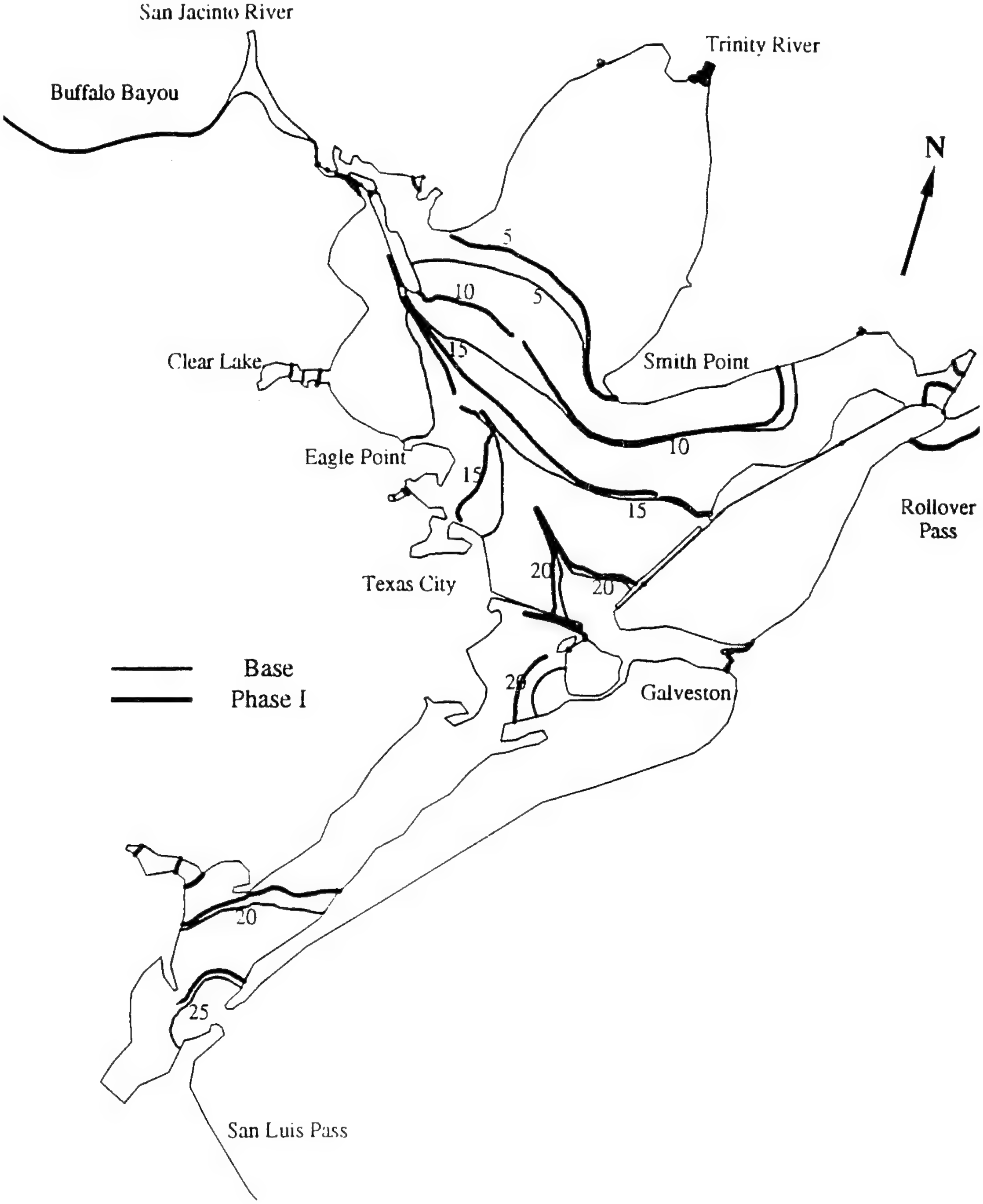


SALINITY CONTOURS, PPT
FEBRUARY 1990, PHASE I
MEDIUM FLOW, BOTTOM

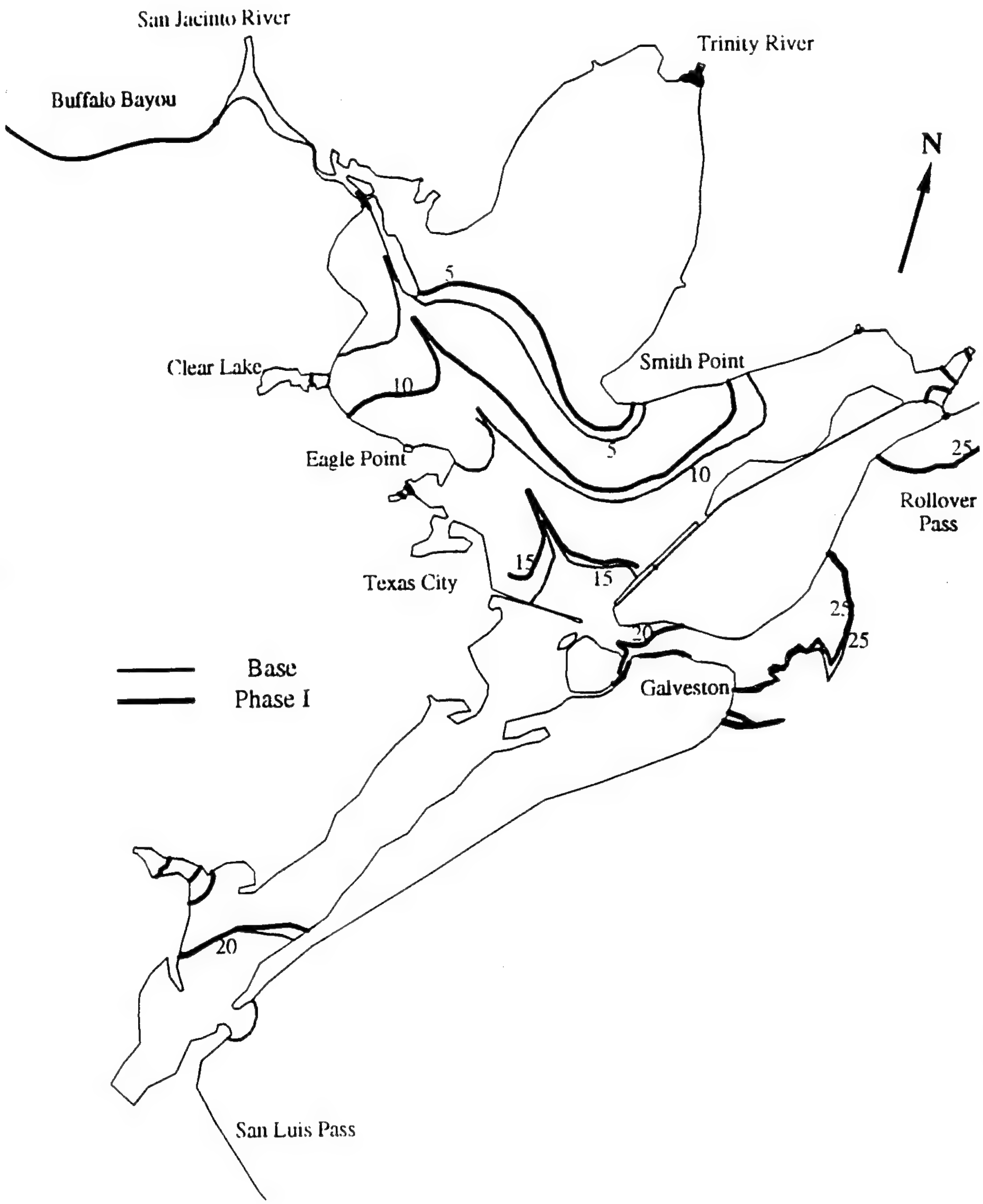
Plate 286



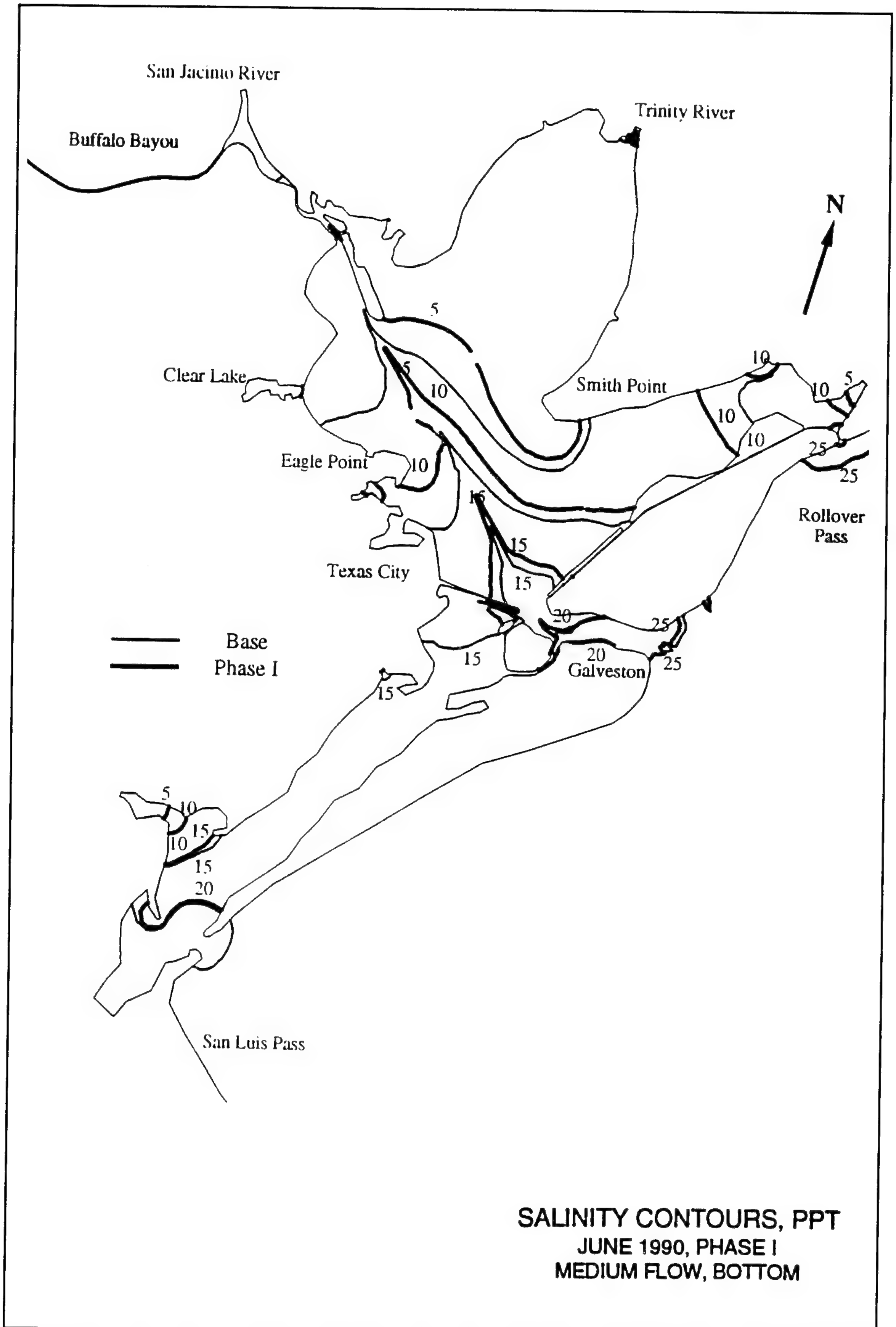
SALINITY CONTOURS, PPT
MARCH 1990, PHASE I
MEDIUM FLOW, BOTTOM



SALINITY CONTOURS, PPT
APRIL 1990, PHASE I
MEDIUM FLOW, BOTTOM



SALINITY CONTOURS, PPT
MAY 1990, PHASE I
MEDIUM FLOW, BOTTOM


San Jacinto River
Buffalo Bayou
Trinity River
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Clear Lake
Smith Point
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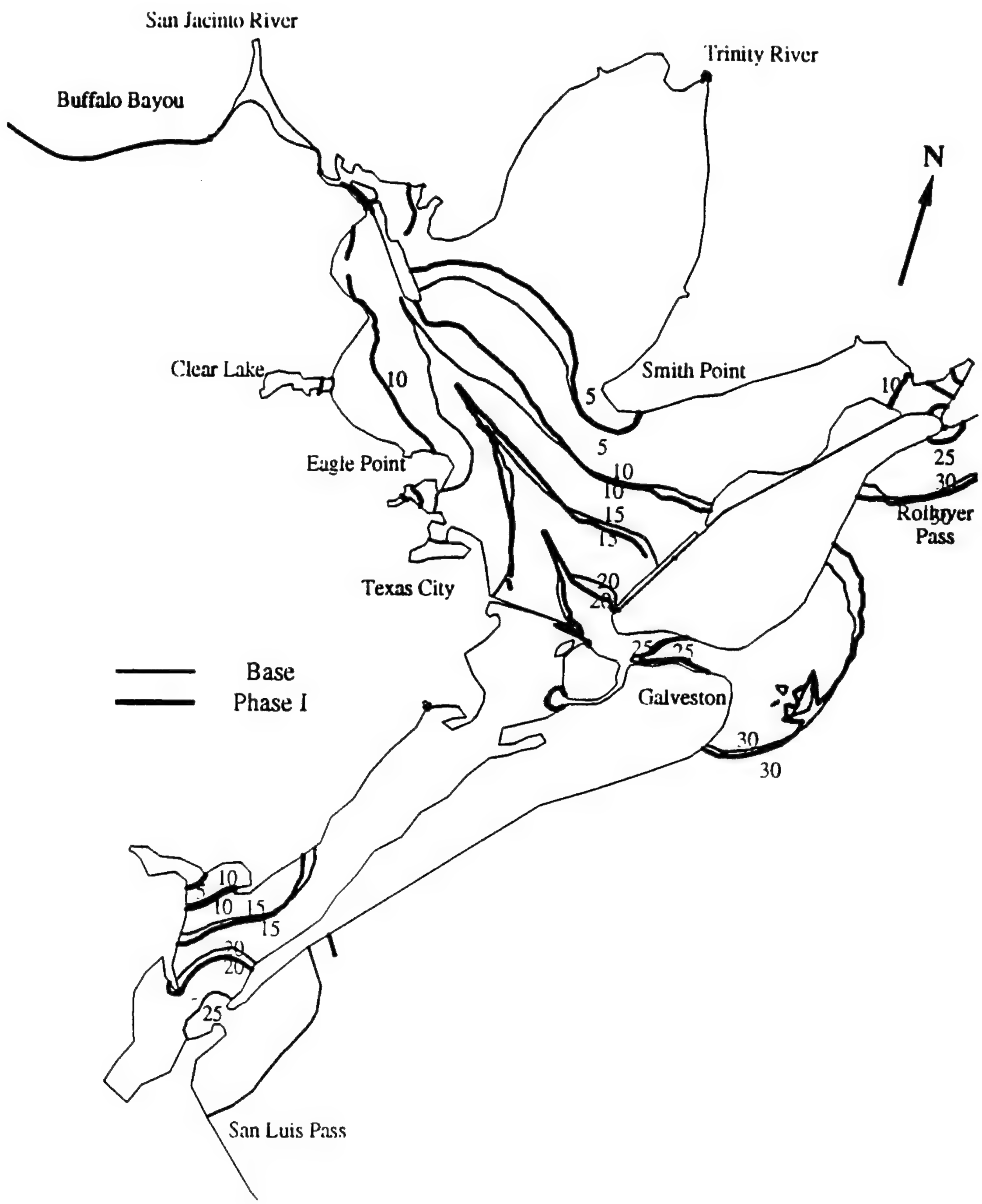
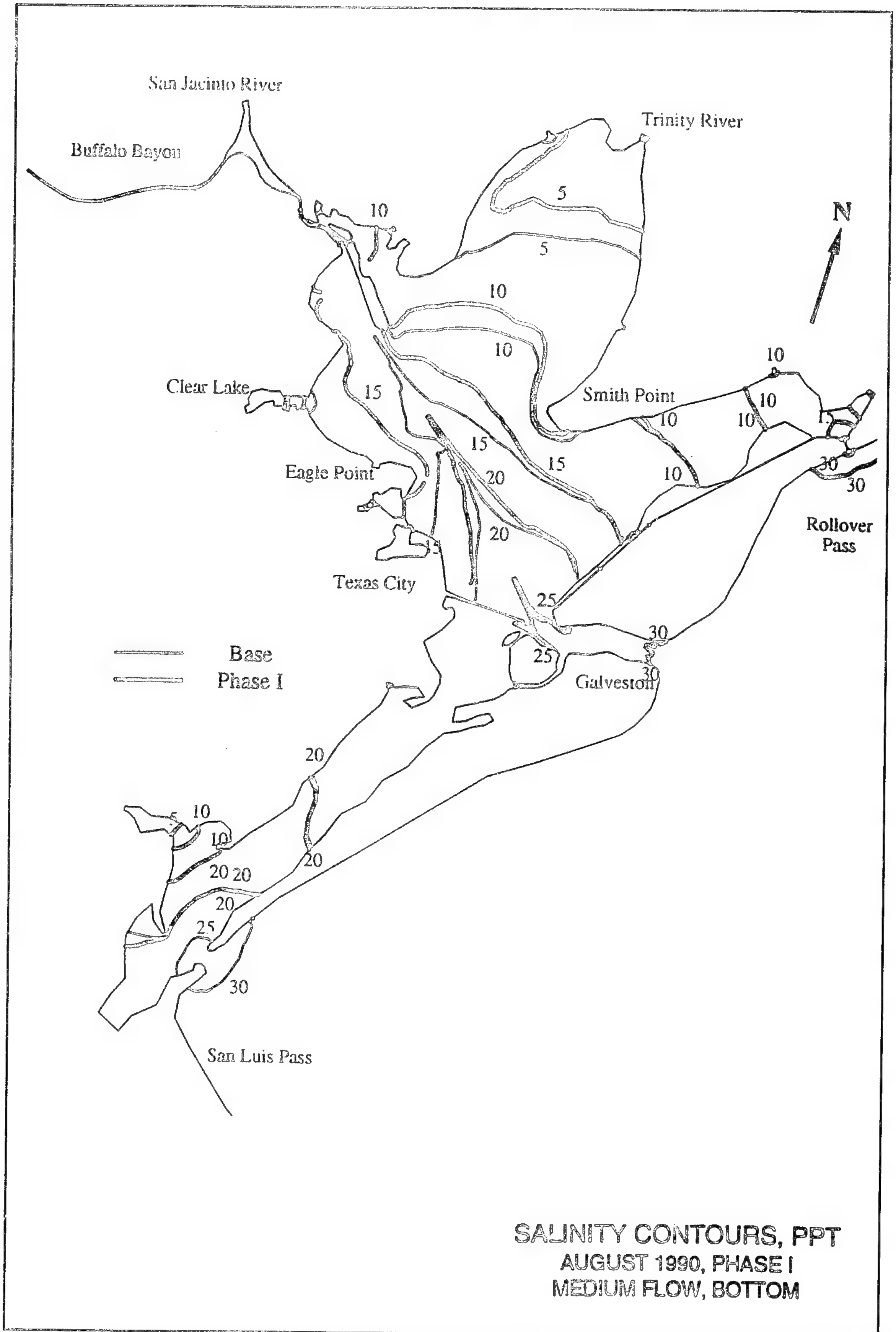
10
10
5
10
25
25
Eagle Point
10
15
15
15
Rollover
Pass
Texas City
20
25
Base
Phase I
15
20
Galveston
25
15
5
10
15
10
15
20
San Luis Pass
SALINITY CONTOURS, PPT
JUNE 1990, PHASE I
MEDIUM FLOW, BOTTOM



SALINITY CONTOURS, PPT
JULY 1990, PHASE I
MEDIUM FLOW, BOTTOM


San Jacinto River
Buffalo Bayou
Trinity River
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Clear Lake
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Smith Point
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10
Eagle Point
15
20
15
10
30
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Rollover Pass
20
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Texas City
25
30
Base
Phase I
25
Galveston
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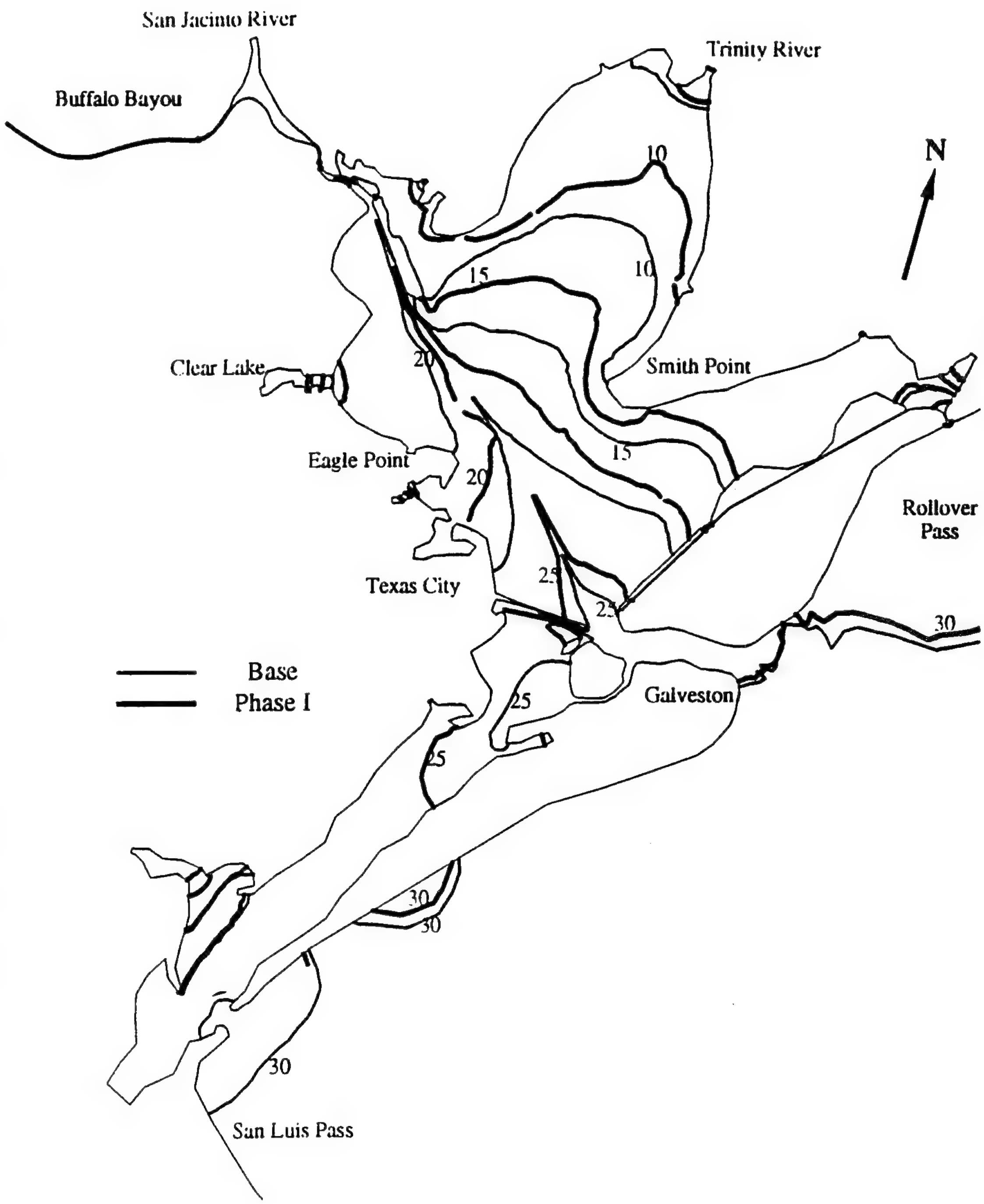
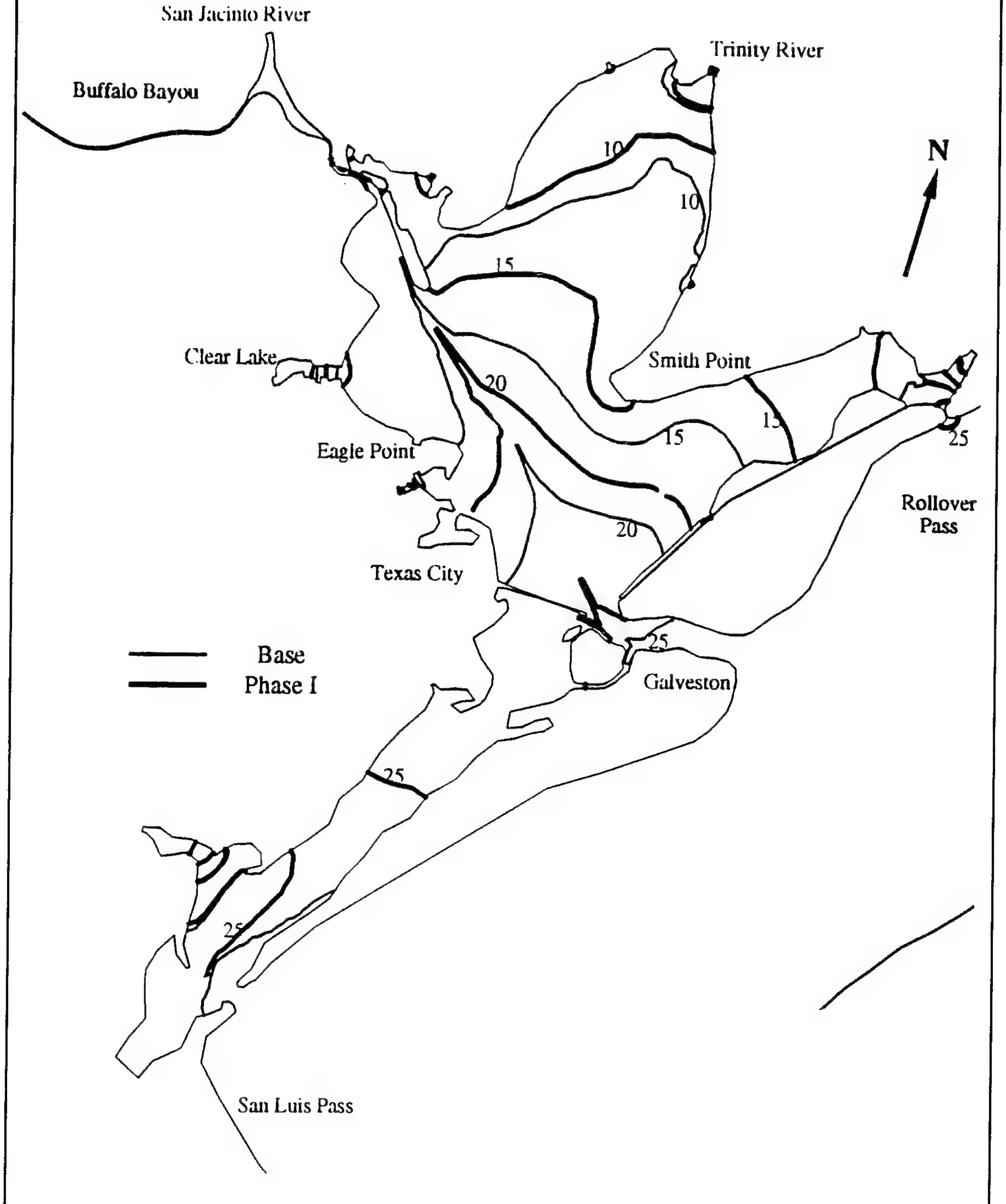
25
30
San Luis Pass
SALINITY CONTOURS, PPT
AUGUST 1990, PHASE I
MEDIUM FLOW, BOTTOM

Plate 292

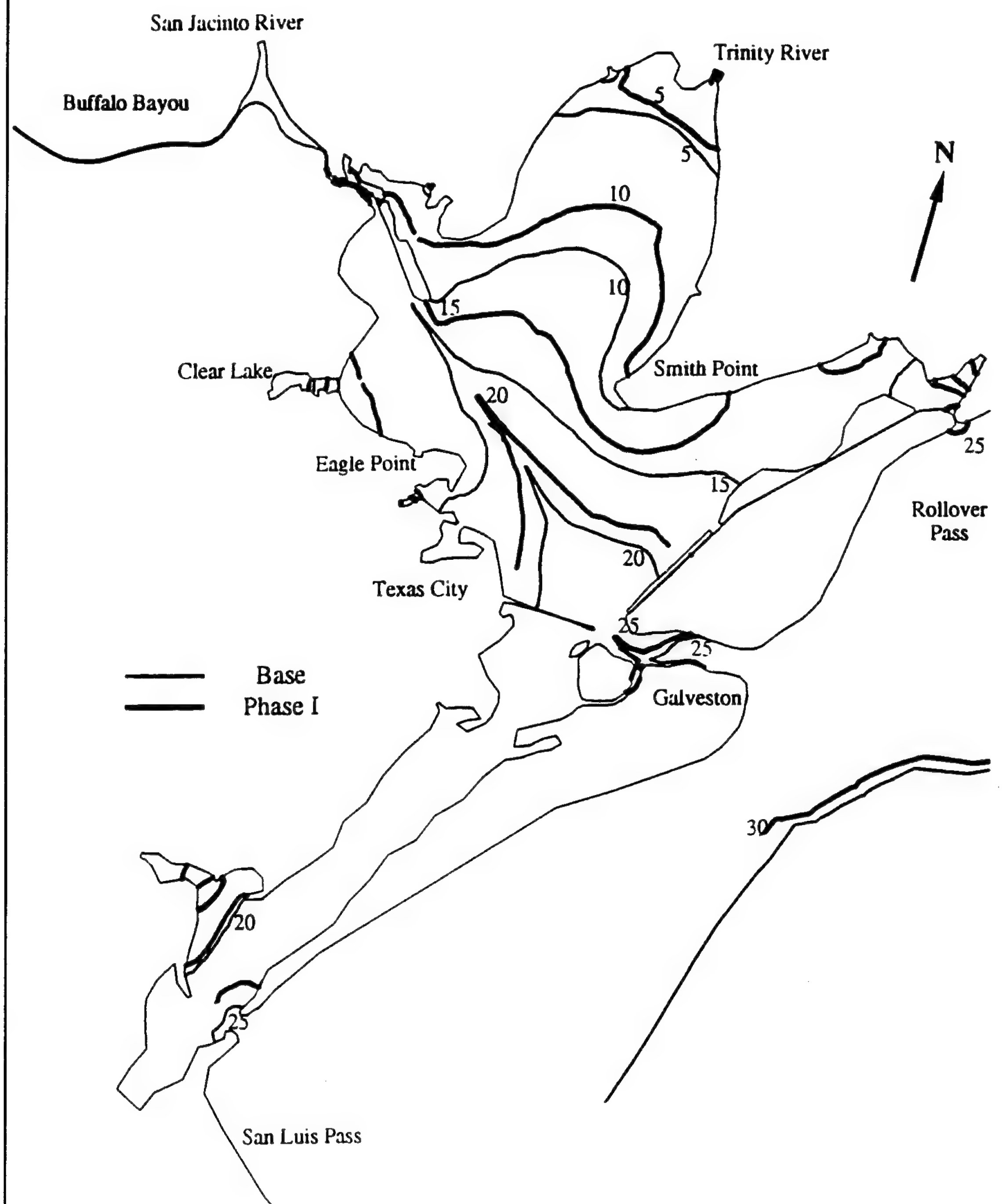


SALINITY CONTOURS, PPT
SEPTEMBER 1990, PHASE I
MEDIUM FLOW, BOTTOM

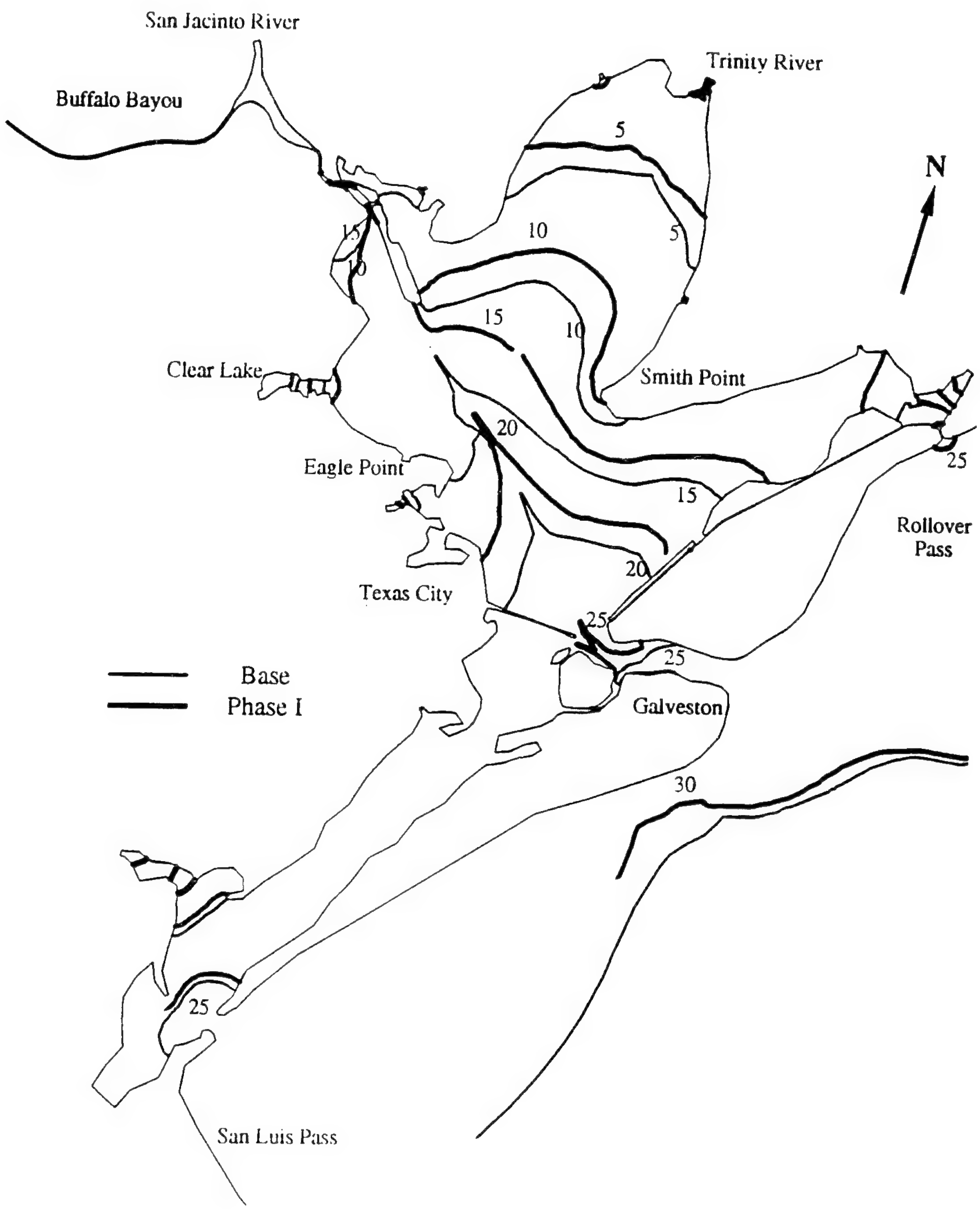


SALINITY CONTOURS, PPT
OCTOBER 1990, PHASE I
MEDIUM FLOW, BOTTOM

Plate 294

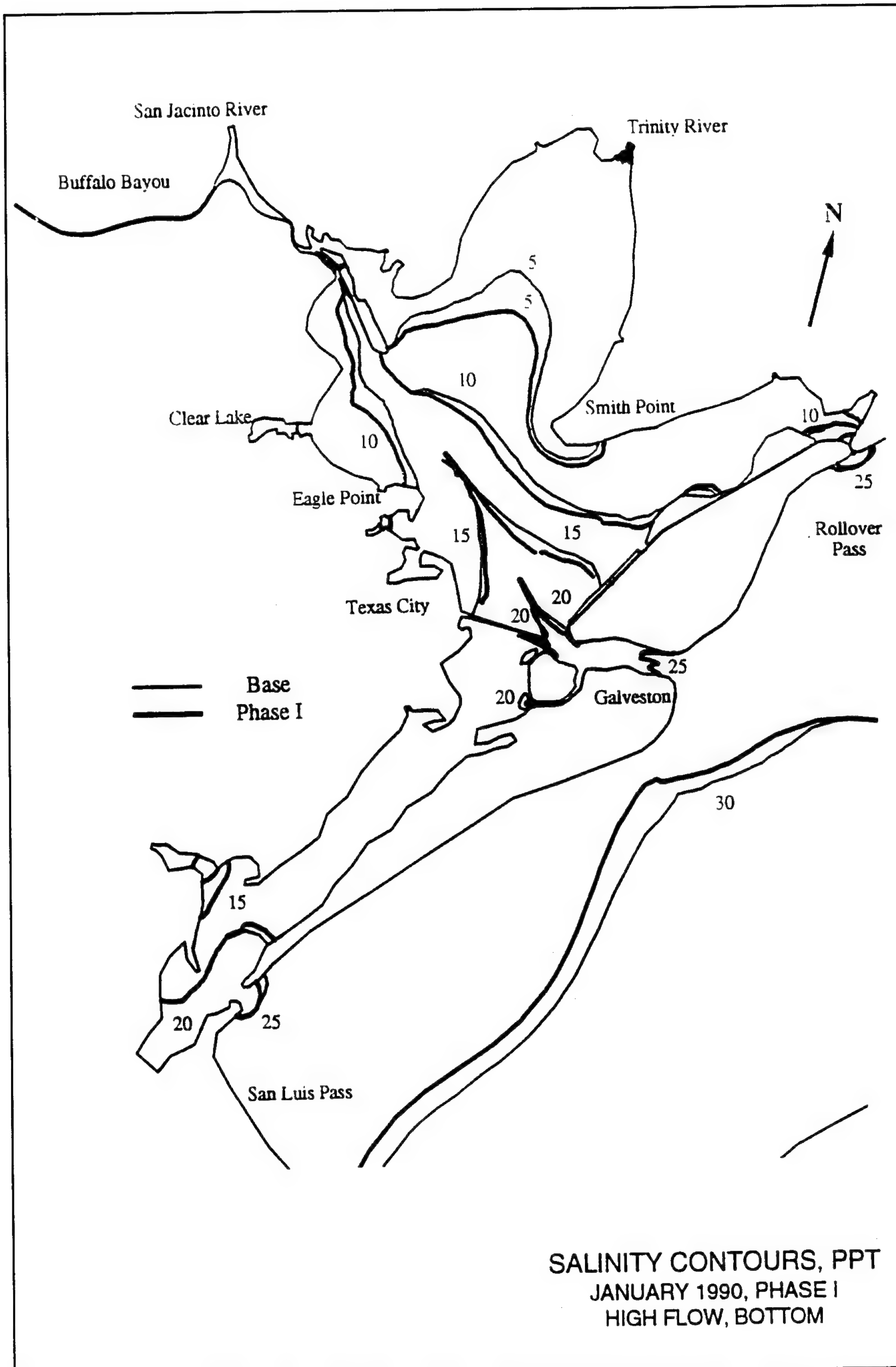


SALINITY CONTOURS, PPT
NOVEMBER 1990, PHASE I
MEDIUM FLOW, BOTTOM



SALINITY CONTOURS, PPT
DECEMBER 1990, PHASE I
MEDIUM FLOW, BOTTOM

Plate 296


San Jacinto River
Trinity River
Buffalo Bayou
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Smith Point
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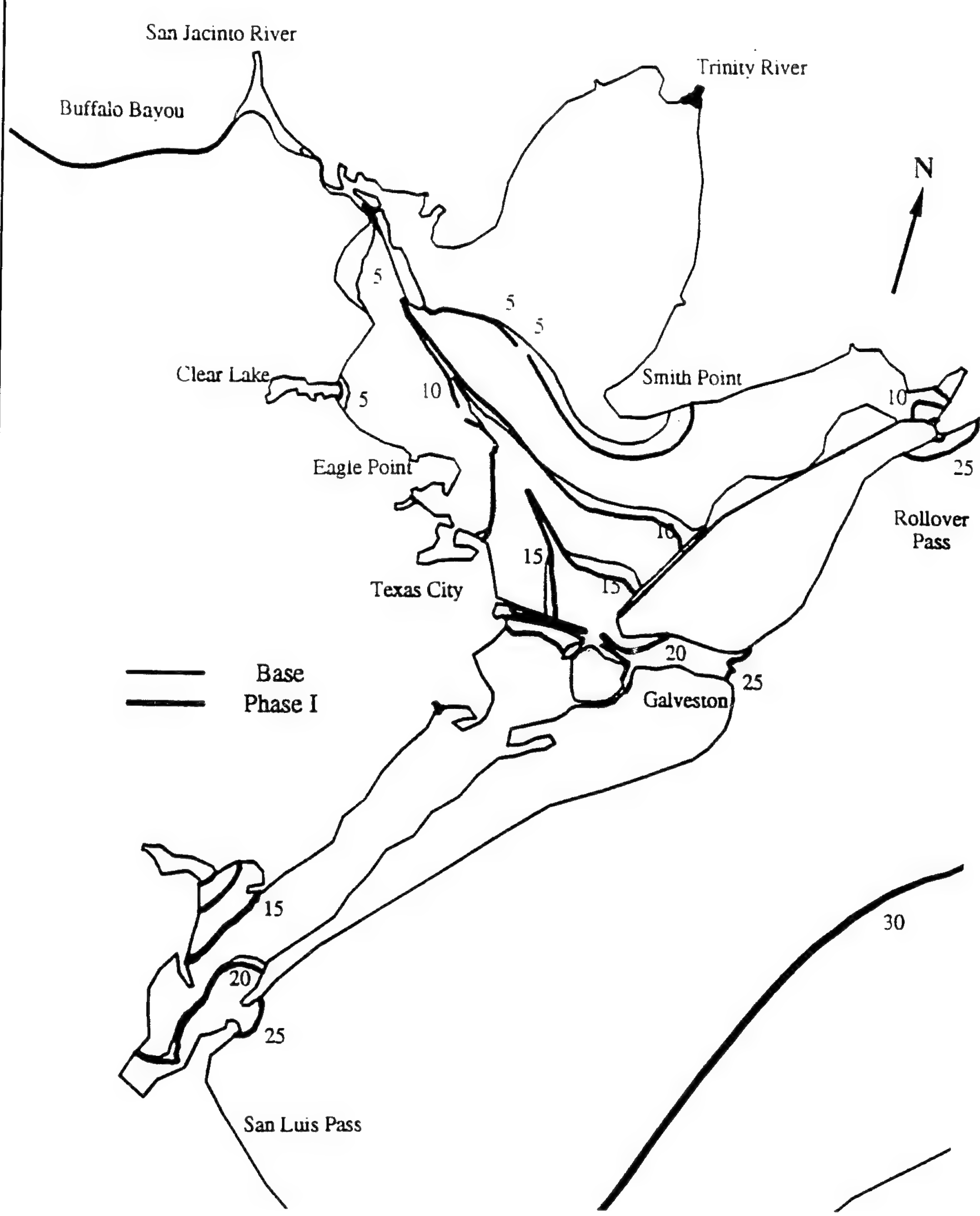
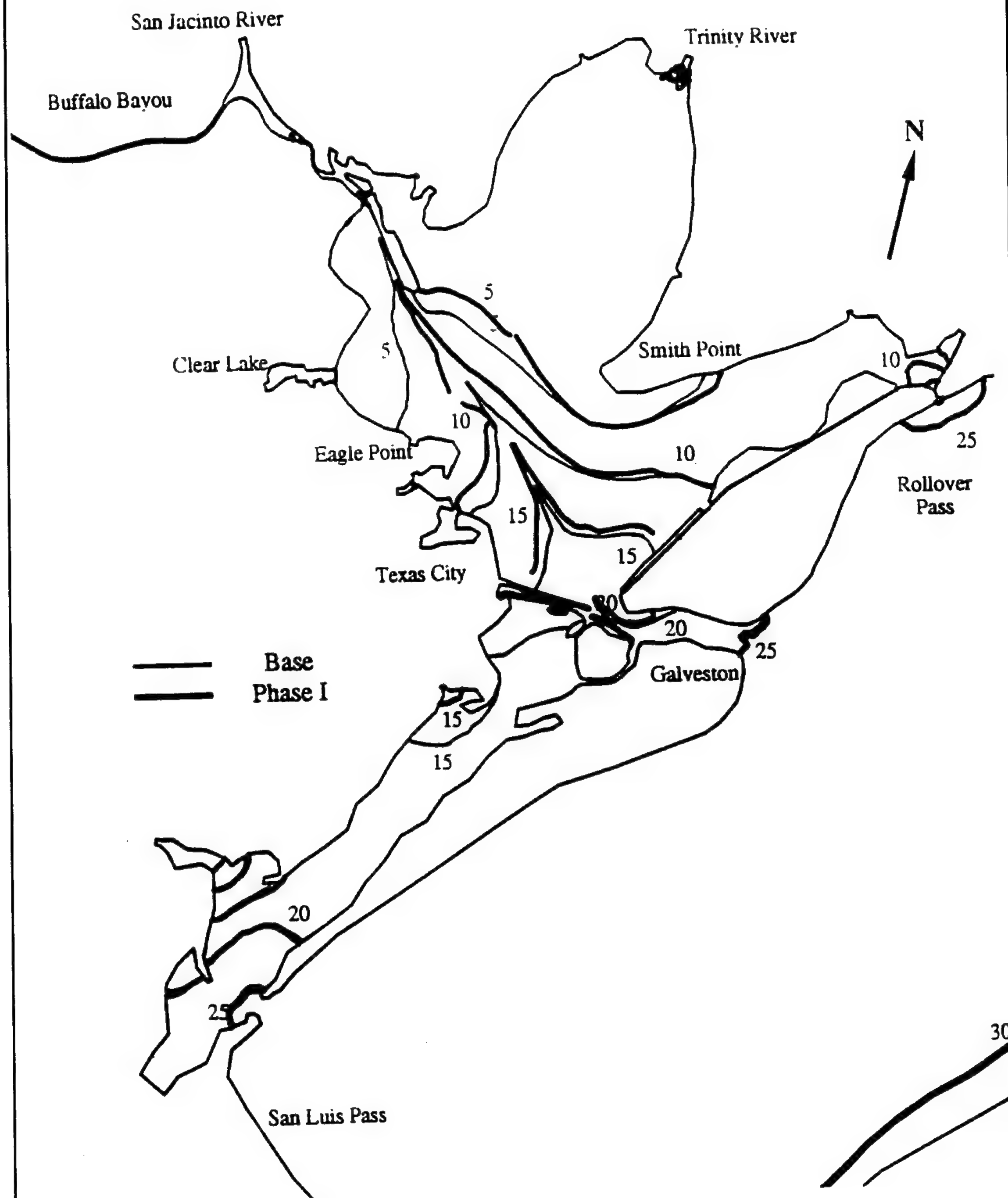
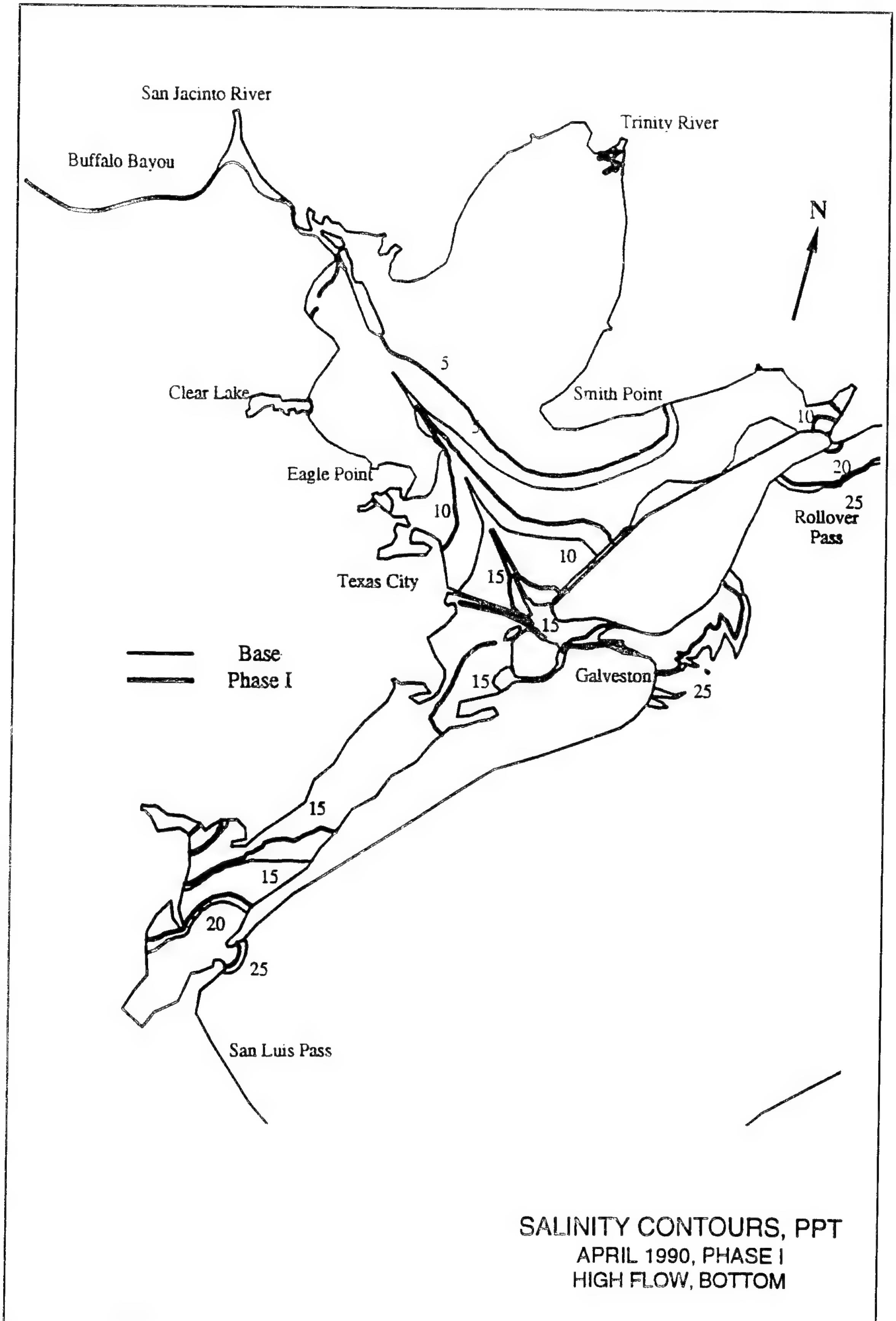
Clear Lake
10
25
Eagle Point
Rollover Pass
15
15
20
Texas City
20
Base
Phase I
20
25
Galveston
30
15
20
25
San Luis Pass
SALINITY CONTOURS, PPT
JANUARY 1990, PHASE I
HIGH FLOW, BOTTOM



SALINITY CONTOURS, PPT
FEBRUARY 1990, PHASE I
HIGH FLOW, BOTTOM



SALINITY CONTOURS, PPT
MARCH 1990, PHASE I
HIGH FLOW, BOTTOM


San Jacinto River
Buffalo Bayou
Trinity River
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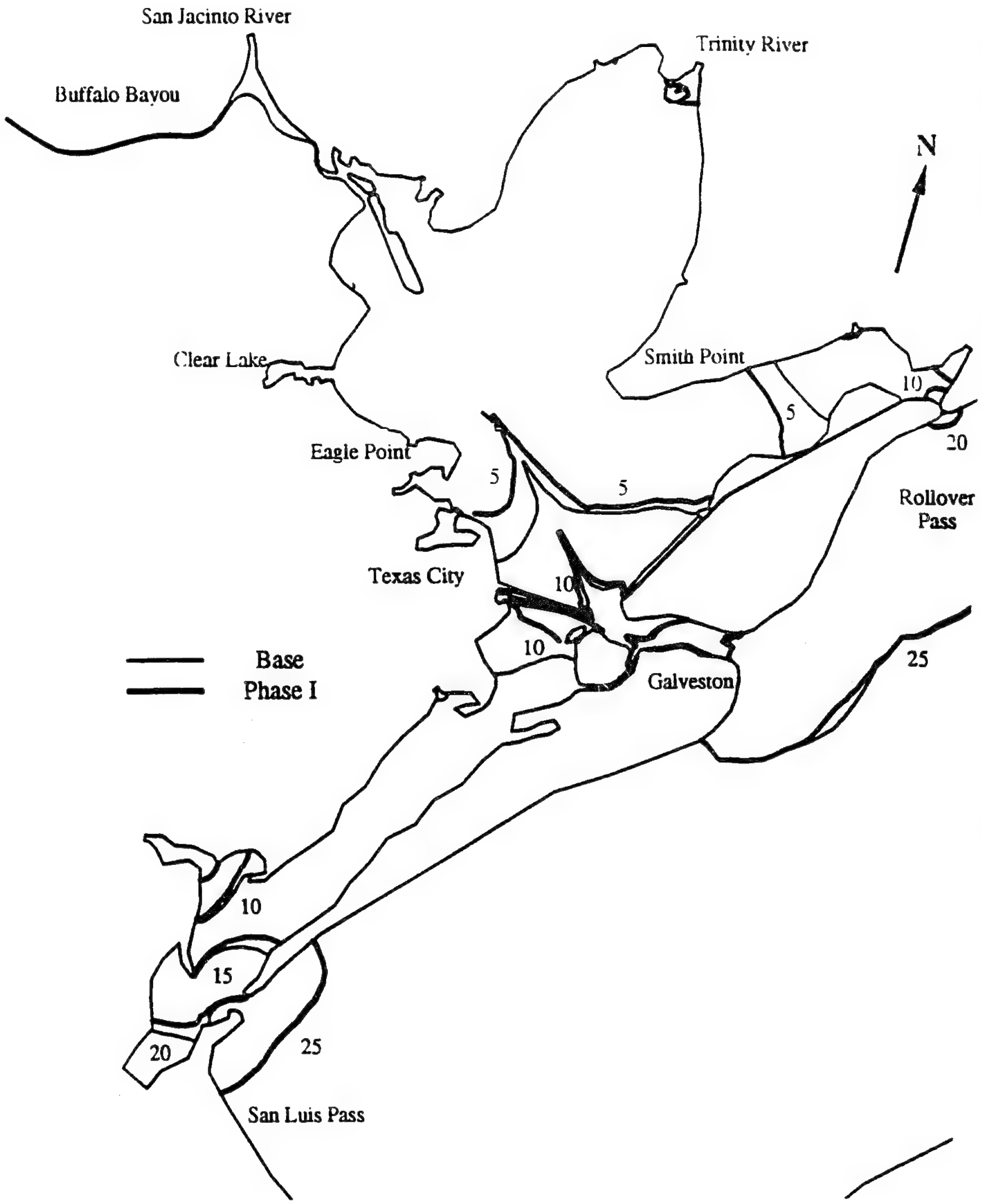
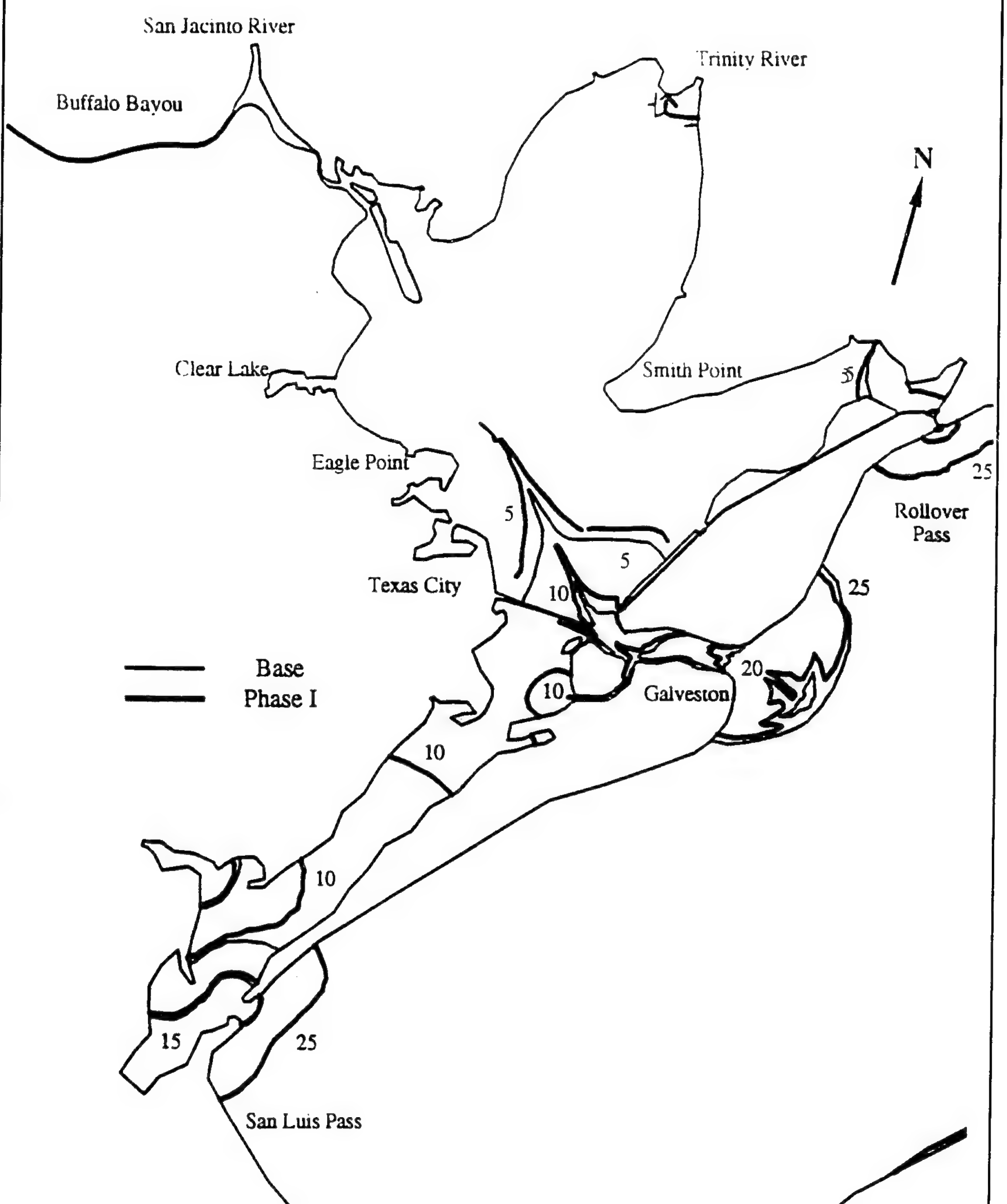
Clear Lake
Smith Point
5
10
Eagle Point
20
10
25
Rollover
Pass
10
Texas City
15
15
Base
Phase I
15
Galveston
25
15
15
20
25
San Luis Pass
SALINITY CONTOURS, PPT
APRIL 1990, PHASE I
HIGH FLOW, BOTTOM

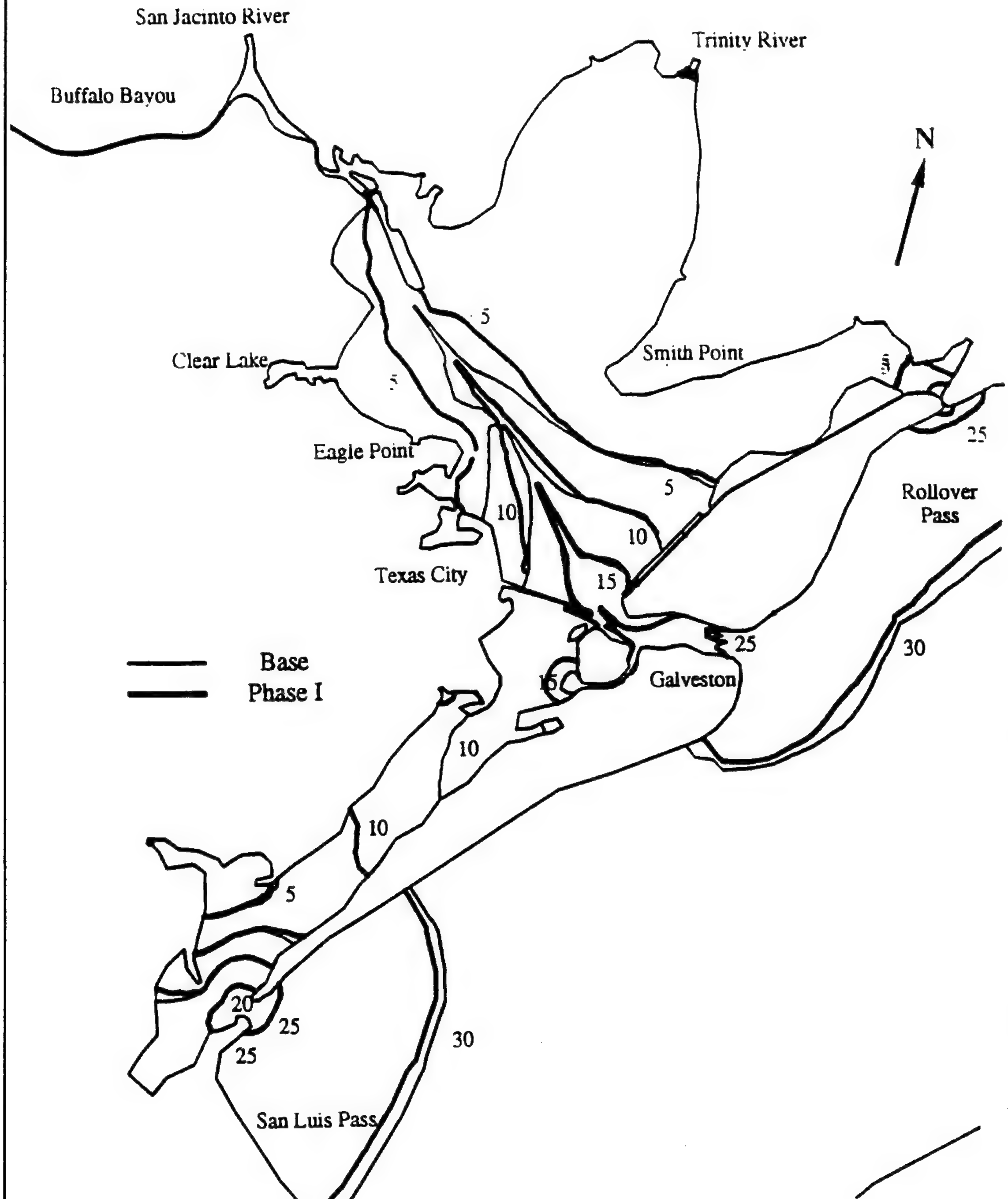
Plate 300



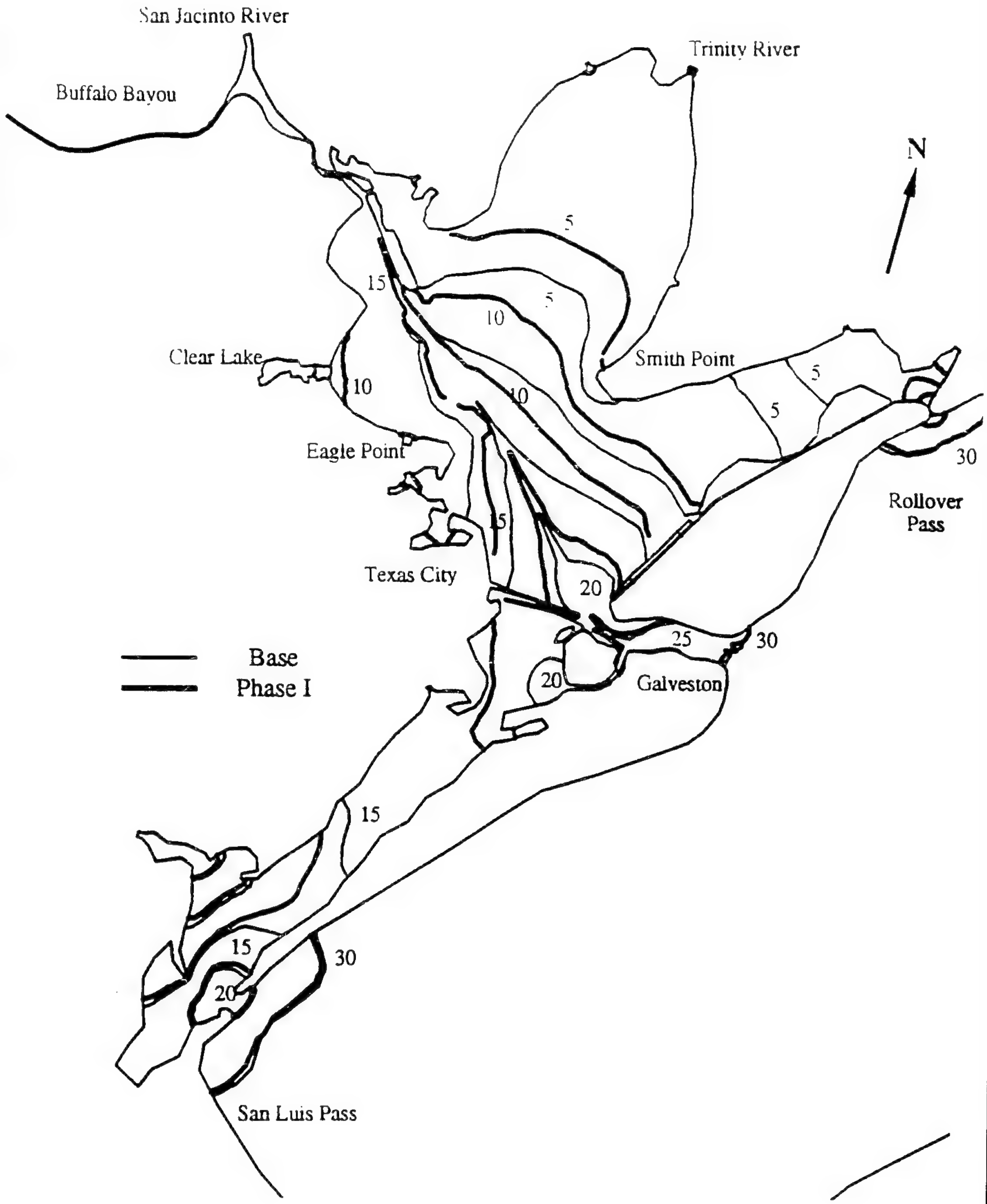
SALINITY CONTOURS, PPT
MAY 1990, PHASE I
HIGH FLOW, BOTTOM



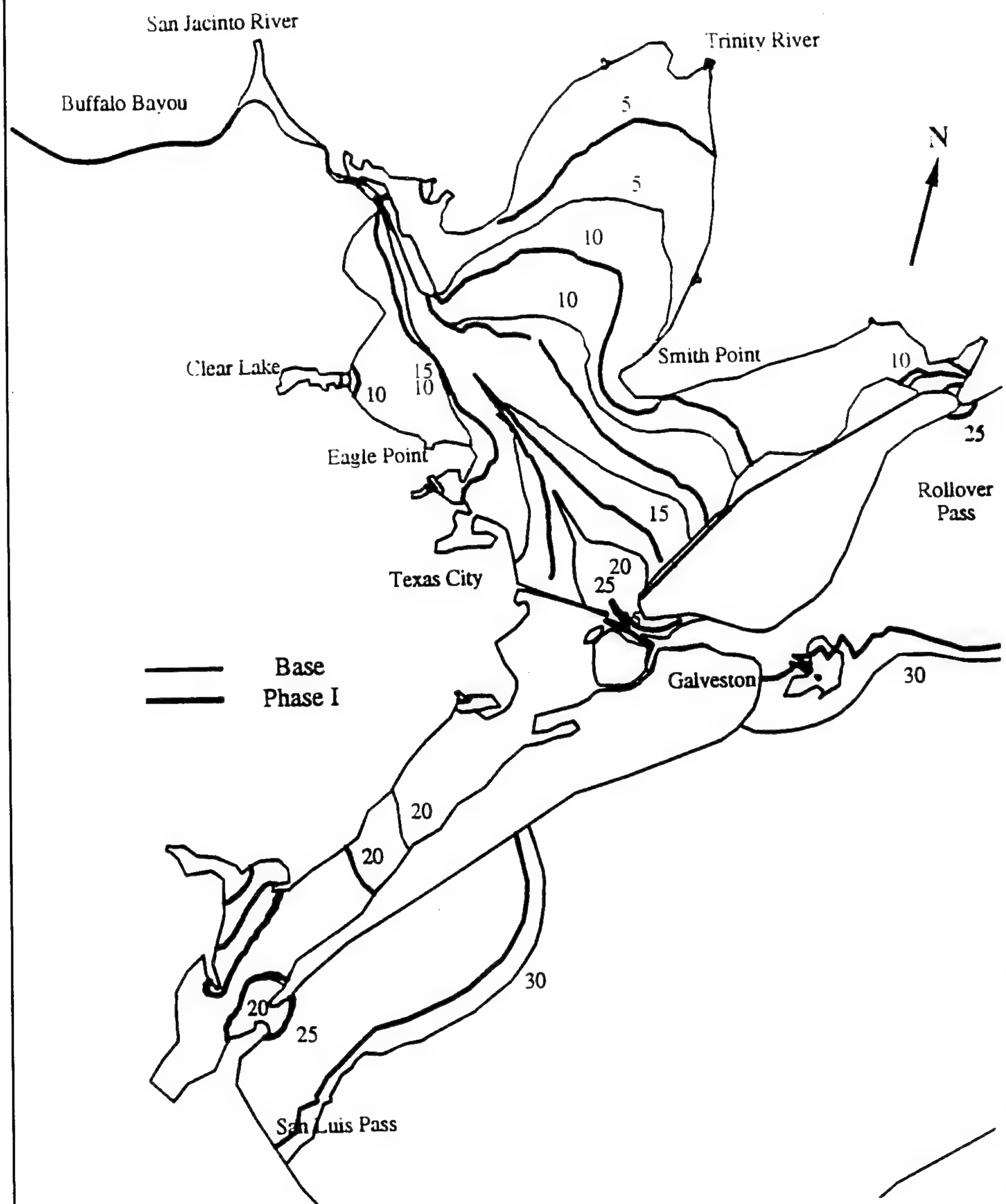
SALINITY CONTOURS, PPT
JUNE 1990, PHASE I
HIGH FLOW, BOTTOM



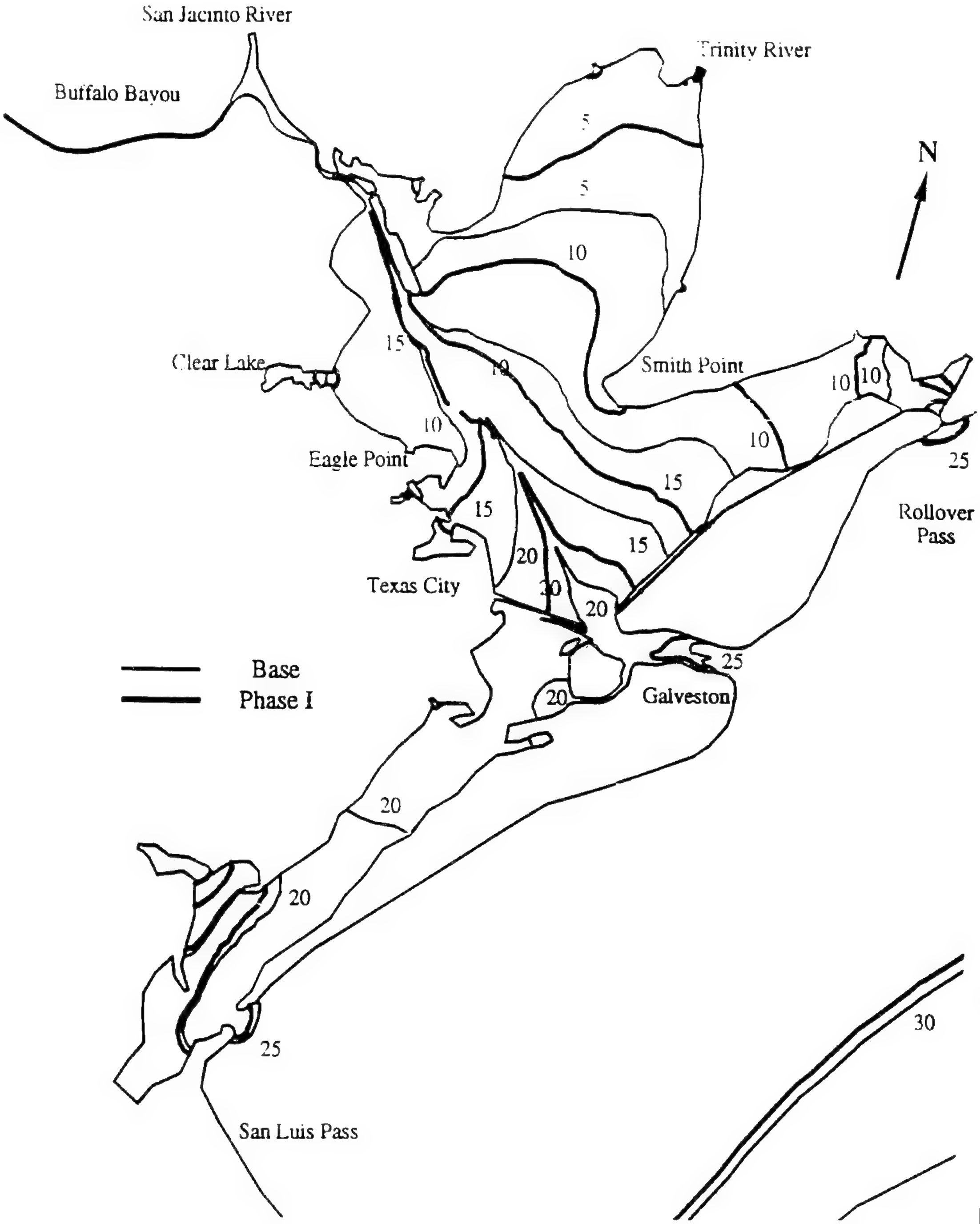
SALINITY CONTOURS, PPT
JULY 1990, PHASE I
HIGH FLOW, BOTTOM



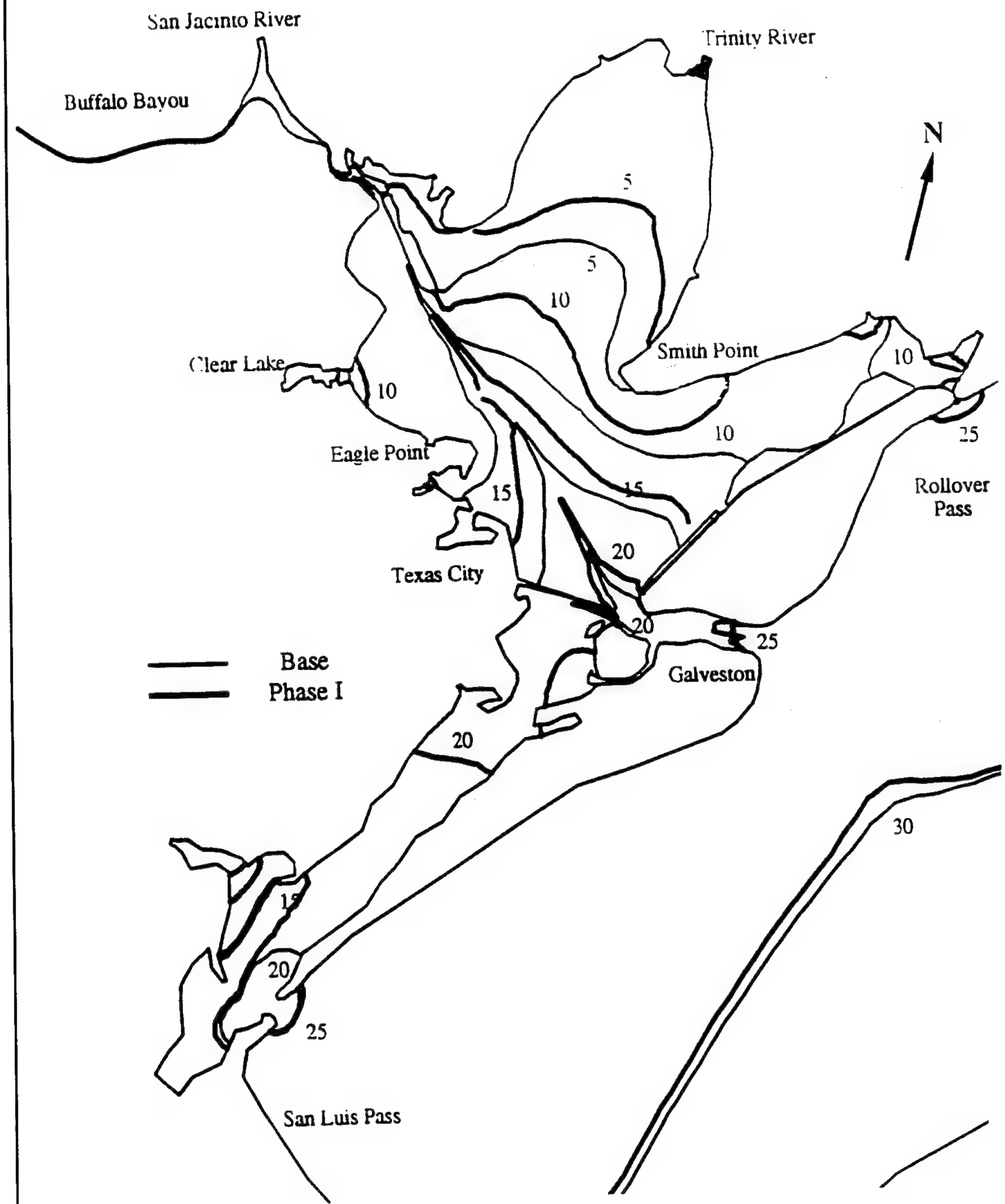
SALINITY CONTOURS, PPT
AUGUST 1990, PHASE I
HIGH FLOW, BOTTOM



SALINITY CONTOURS, PPT
SEPTEMBER 1990, PHASE I
HIGH FLOW, BOTTOM

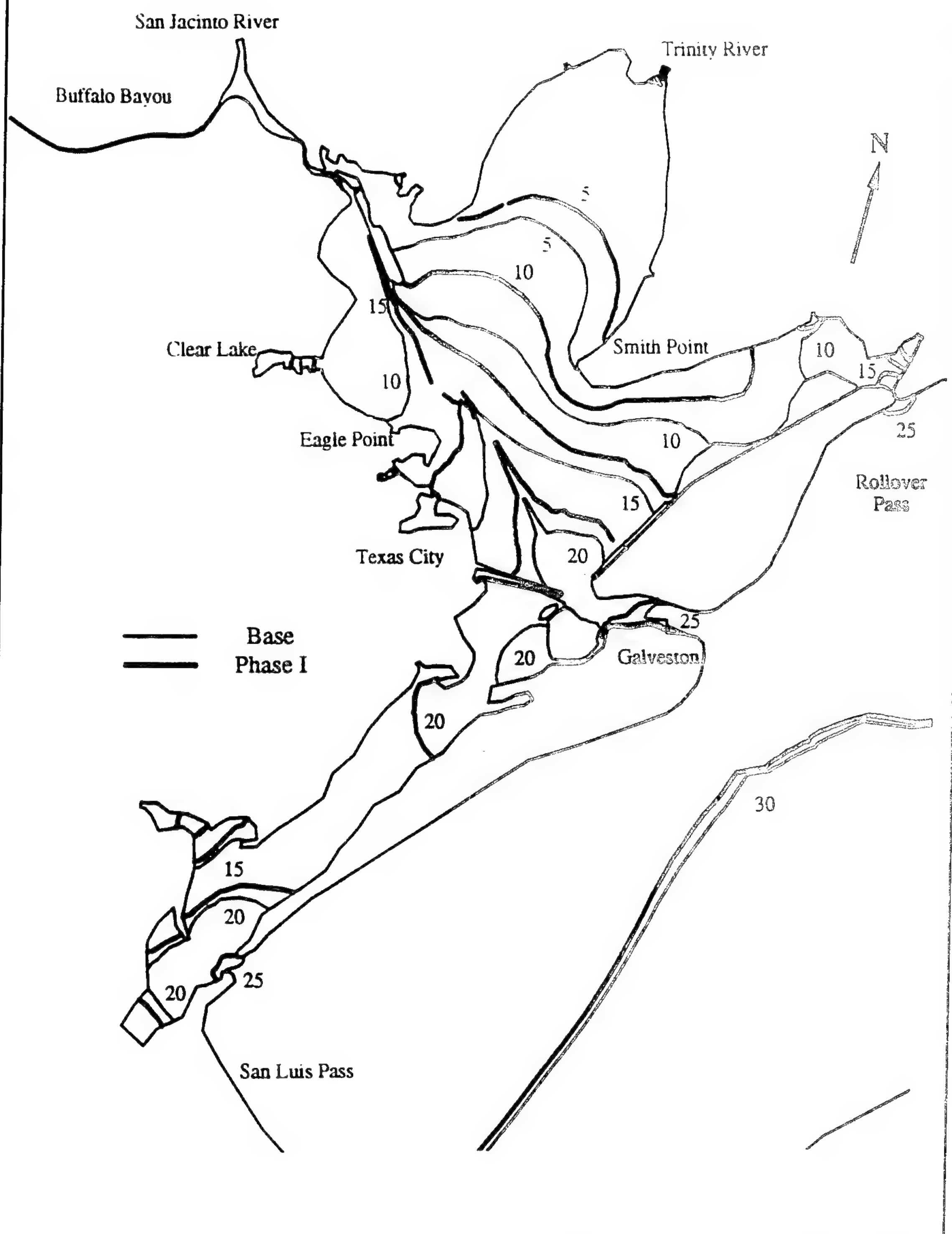


SALINITY CONTOURS, PPT
OCTOBER 1990, PHASE I
HIGH FLOW, BOTTOM

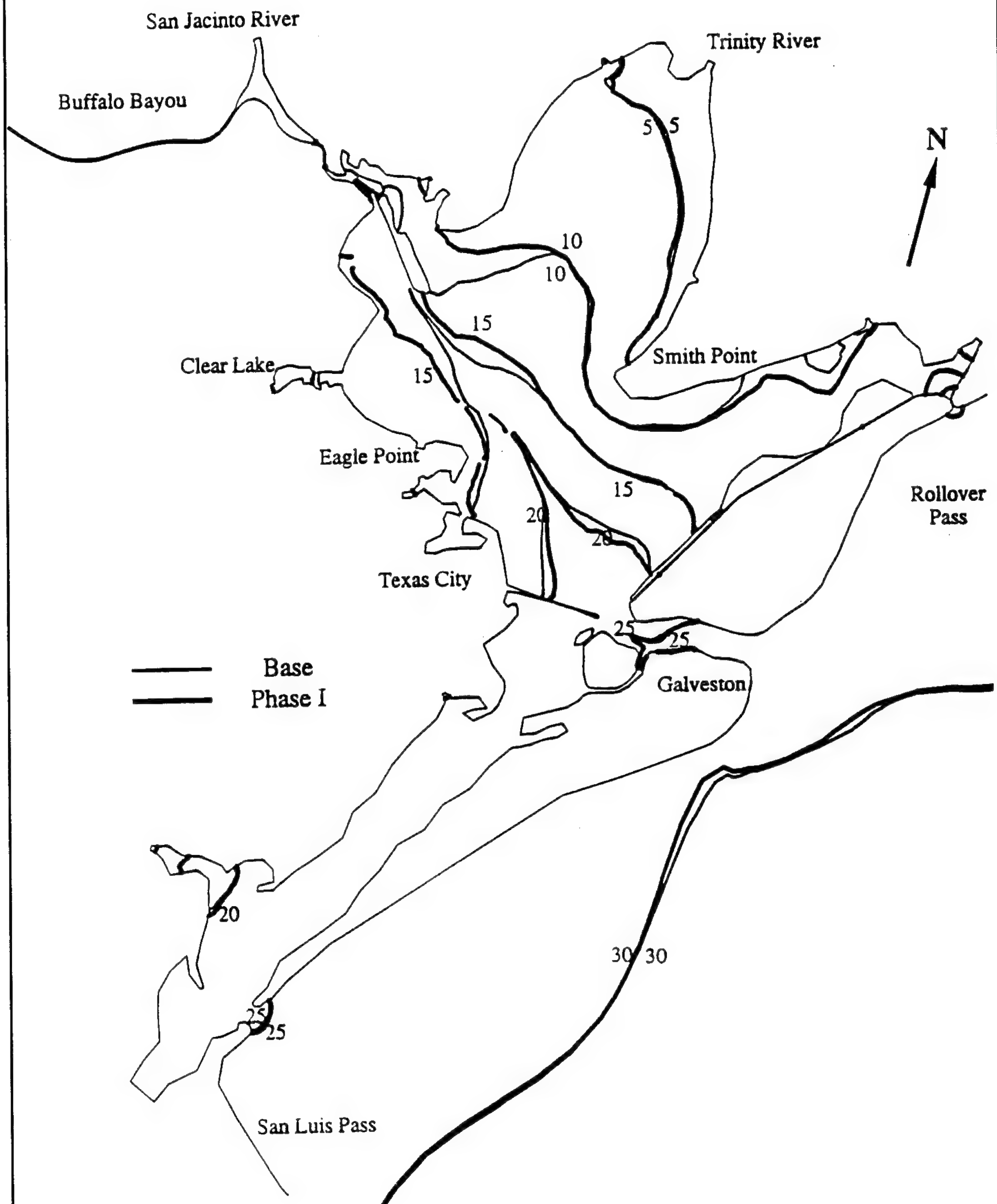


SALINITY CONTOURS, PPT
NOVEMBER 1990, PHASE I
HIGH FLOW, BOTTOM

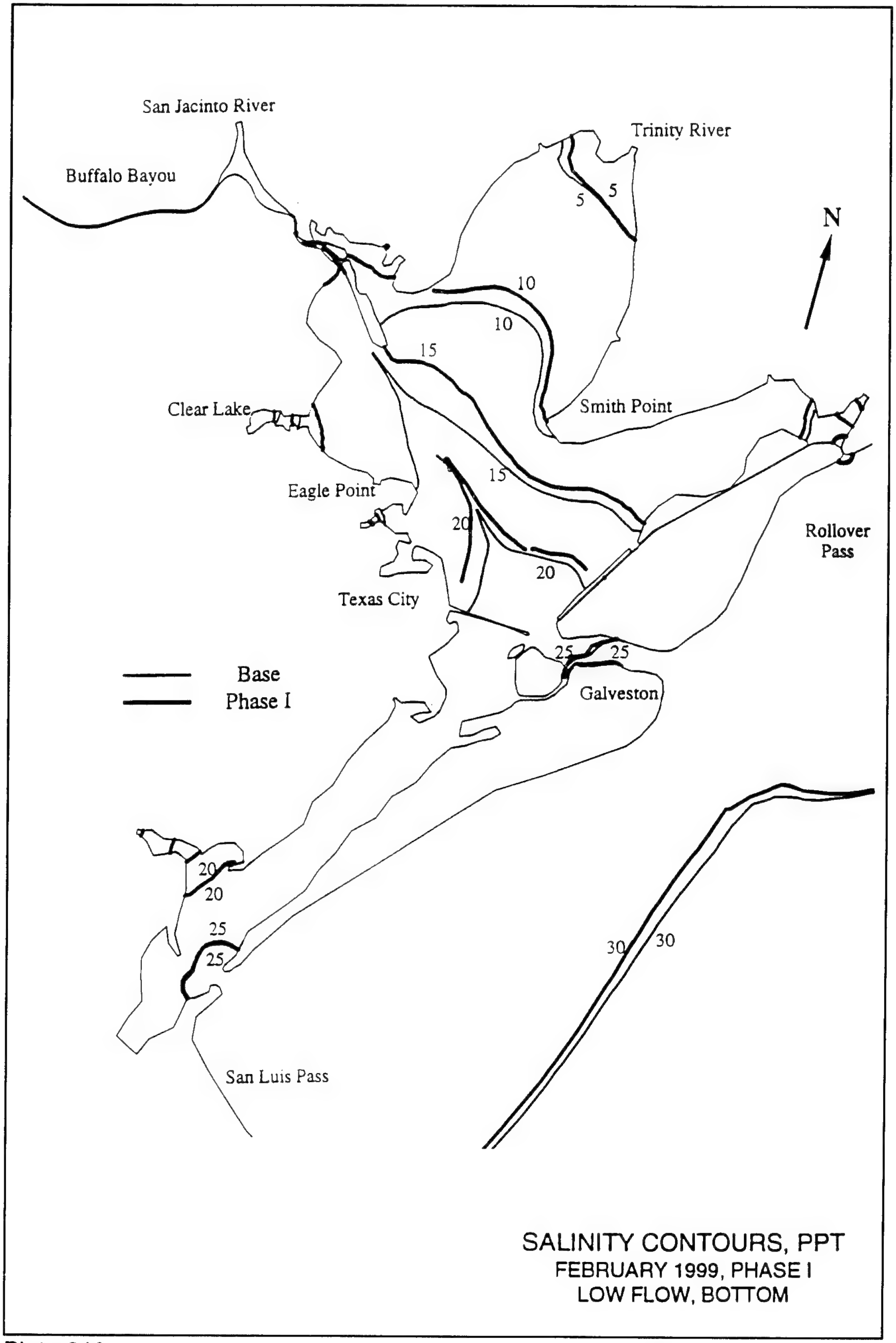
Plate 307



SALINITY CONTOURS, PPT
DECEMBER 1990, PHASE I
HIGH FLOW, BOTTOM



SALINITY CONTOURS, PPT
JANUARY 1999, PHASE I
LOW FLOW, BOTTOM


San Jacinto River
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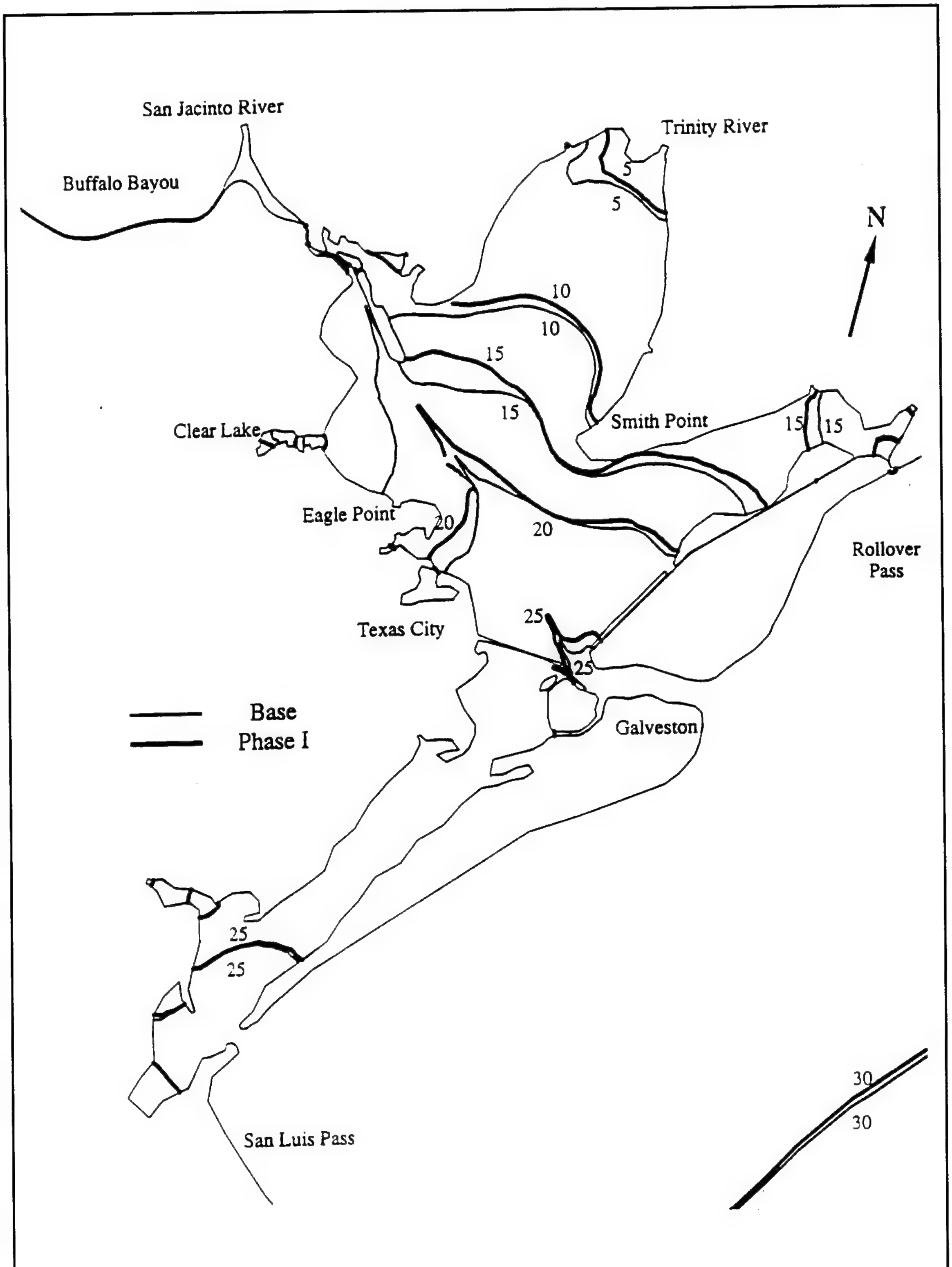
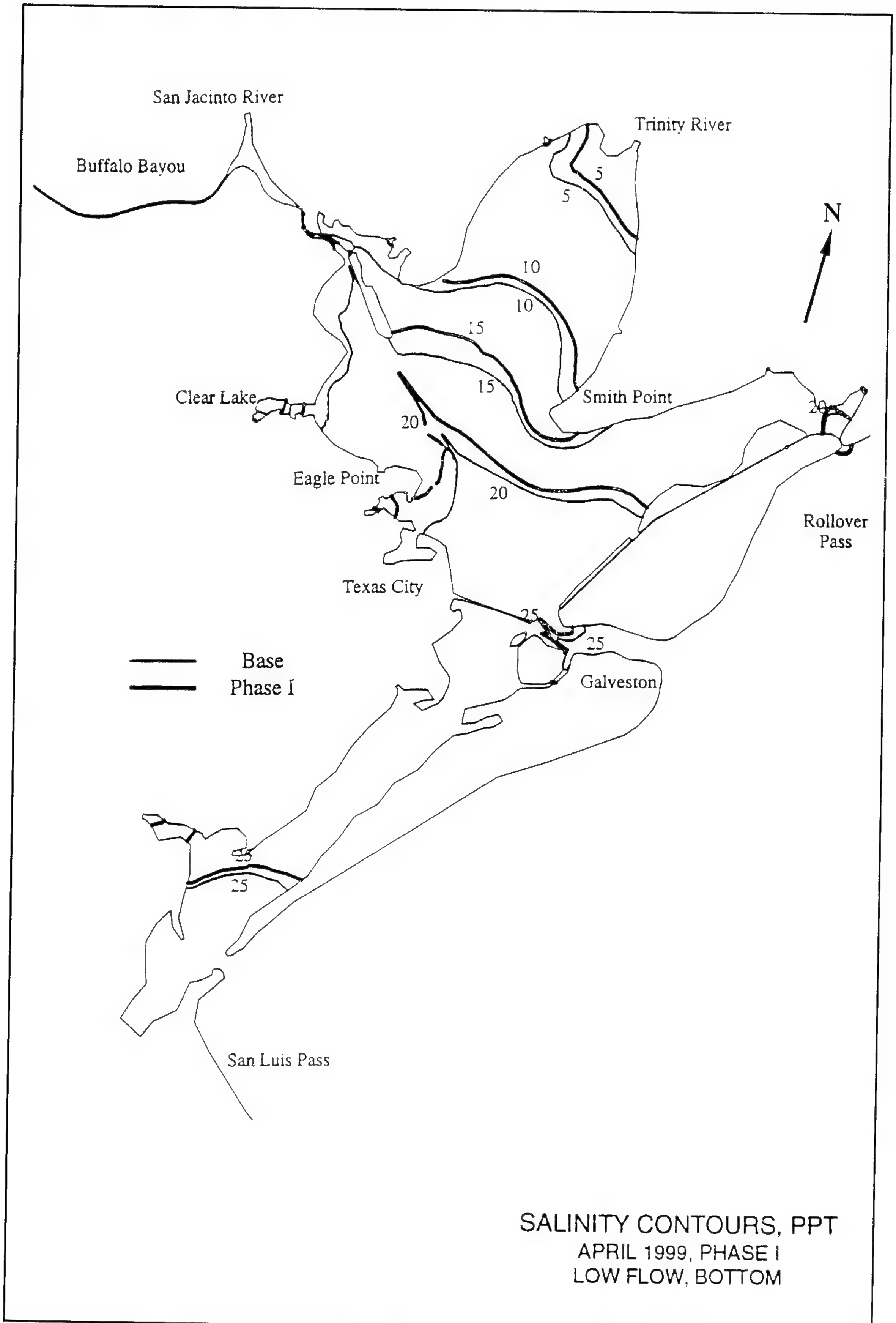
San Luis Pass
SALINITY CONTOURS, PPT
FEBRUARY 1999, PHASE I
LOW FLOW, BOTTOM

Plate 310



SALINITY CONTOURS, PPT
MARCH 1999, PHASE I
LOW FLOW, BOTTOM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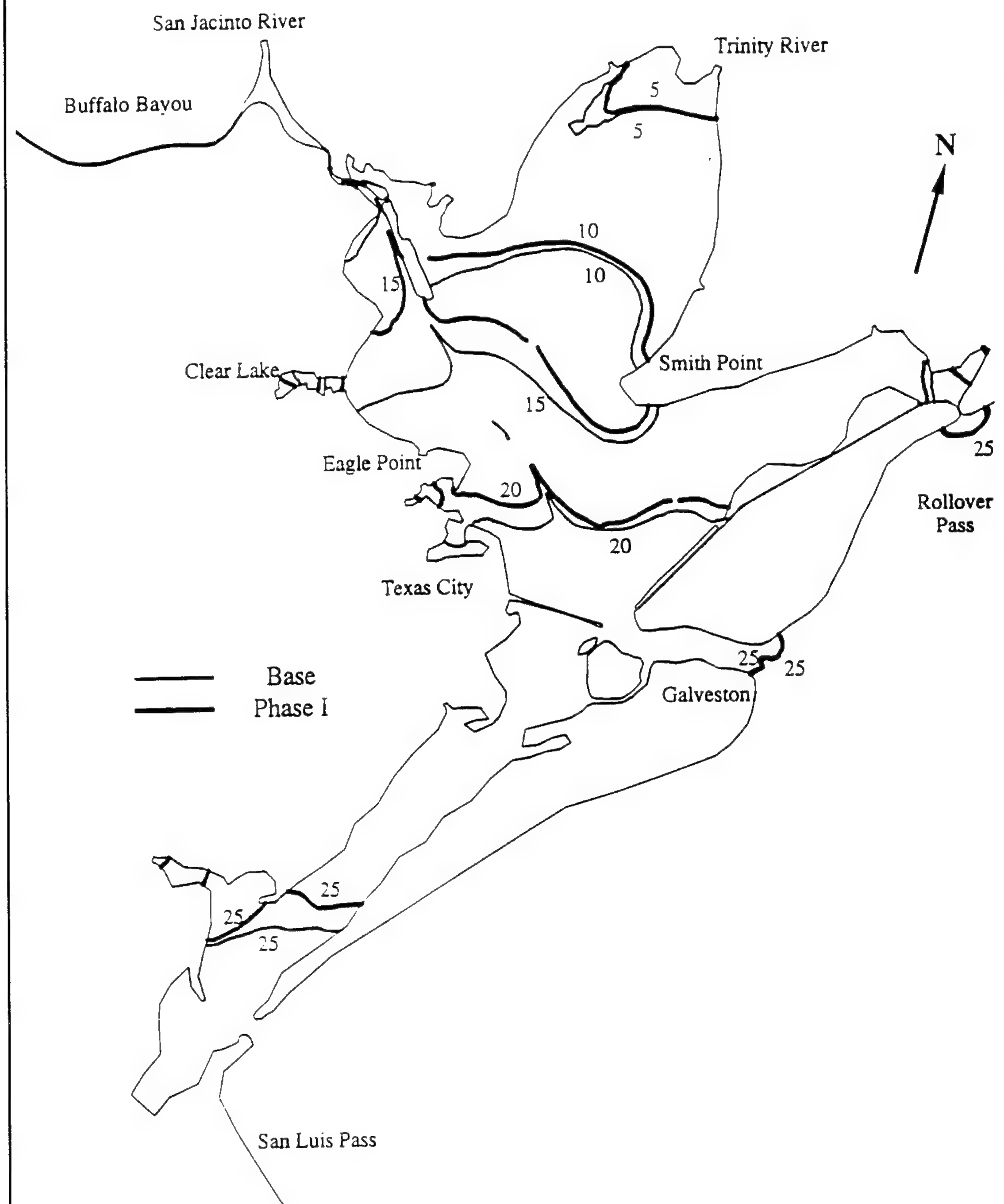
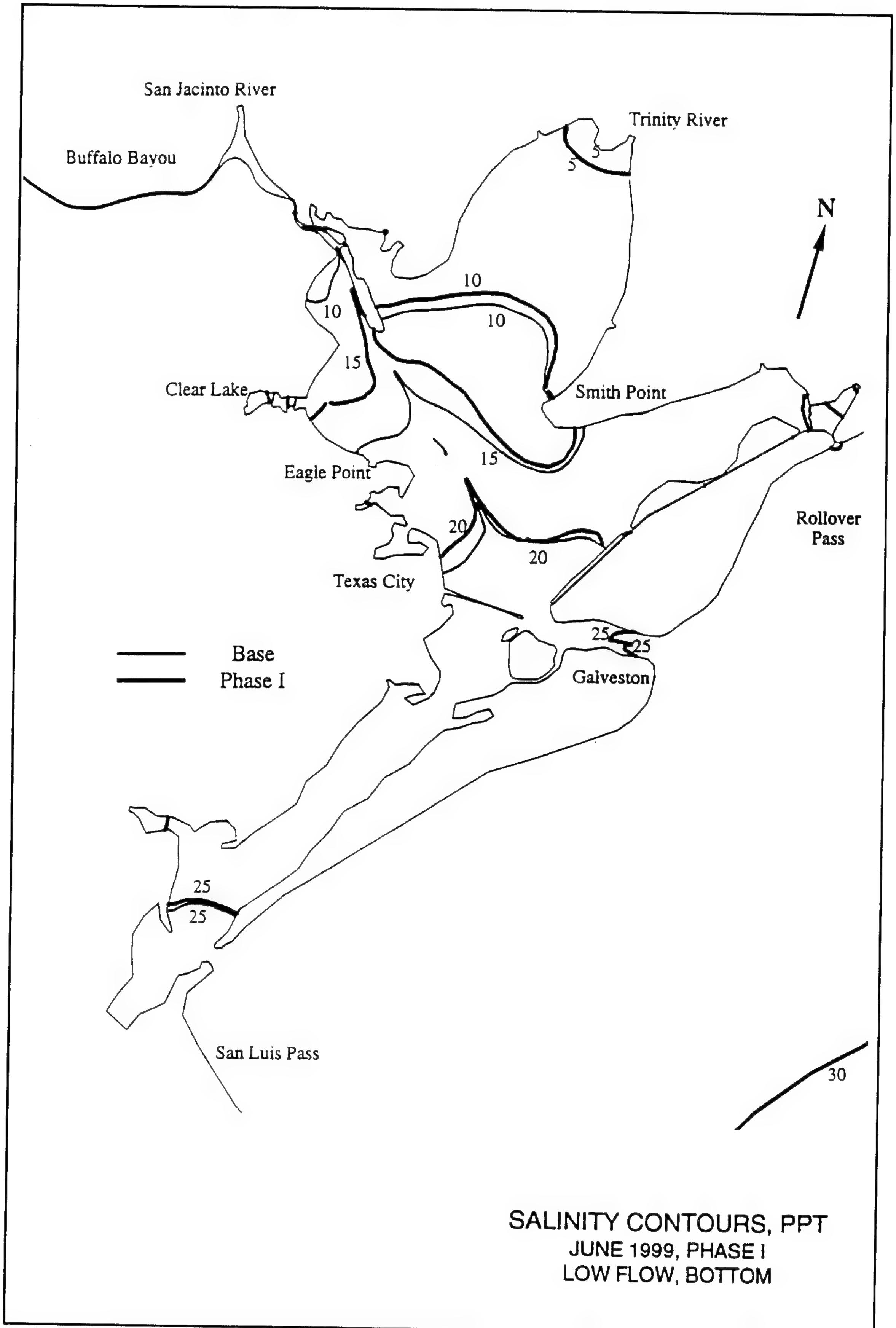
San Luis Pass
SALINITY CONTOURS, PPT
APRIL 1999, PHASE I
LOW FLOW, BOTTOM

Plate 312



SALINITY CONTOURS, PPT
MAY 1999, PHASE I
LOW FLOW, BOTTOM


San Jacinto River
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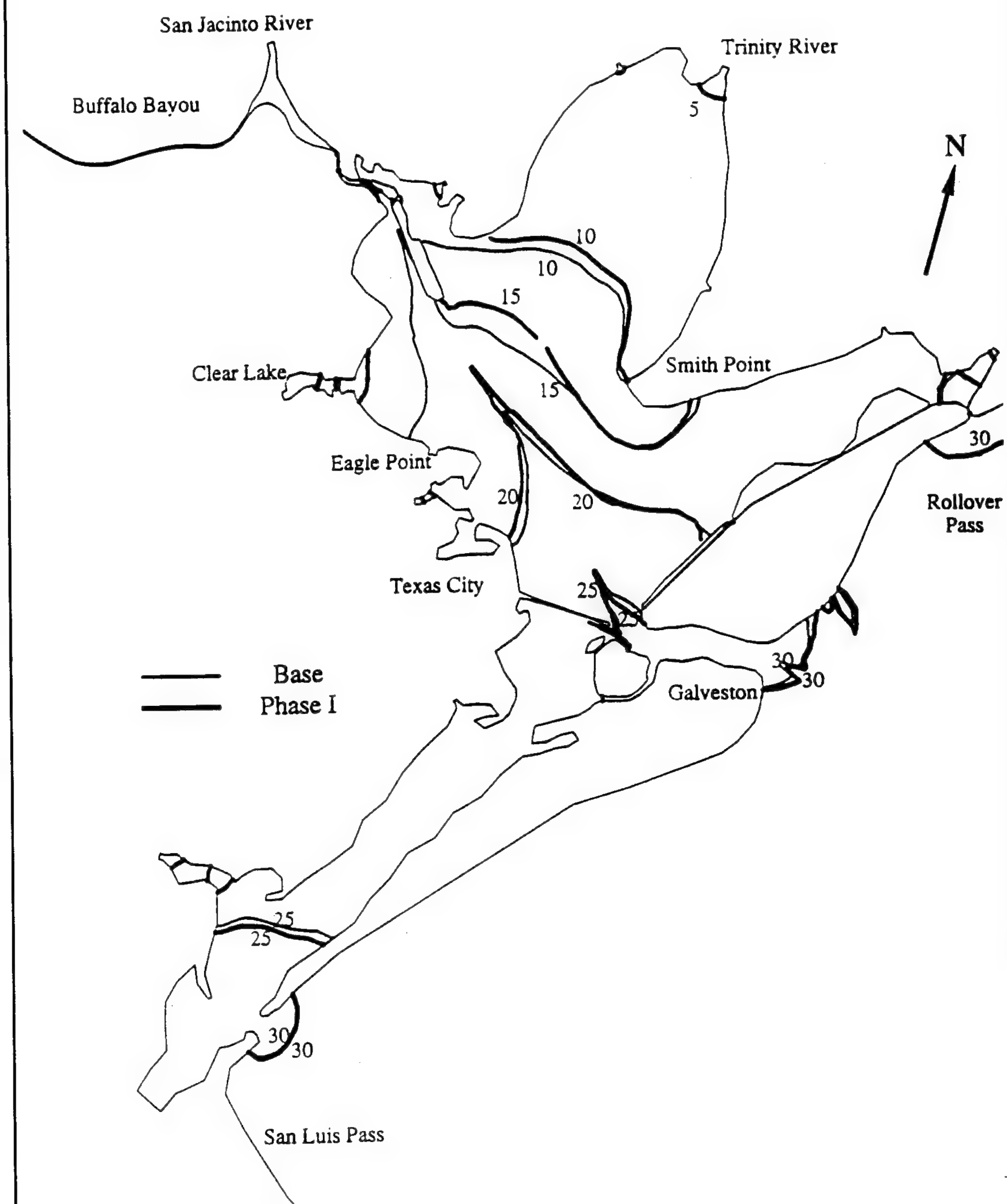
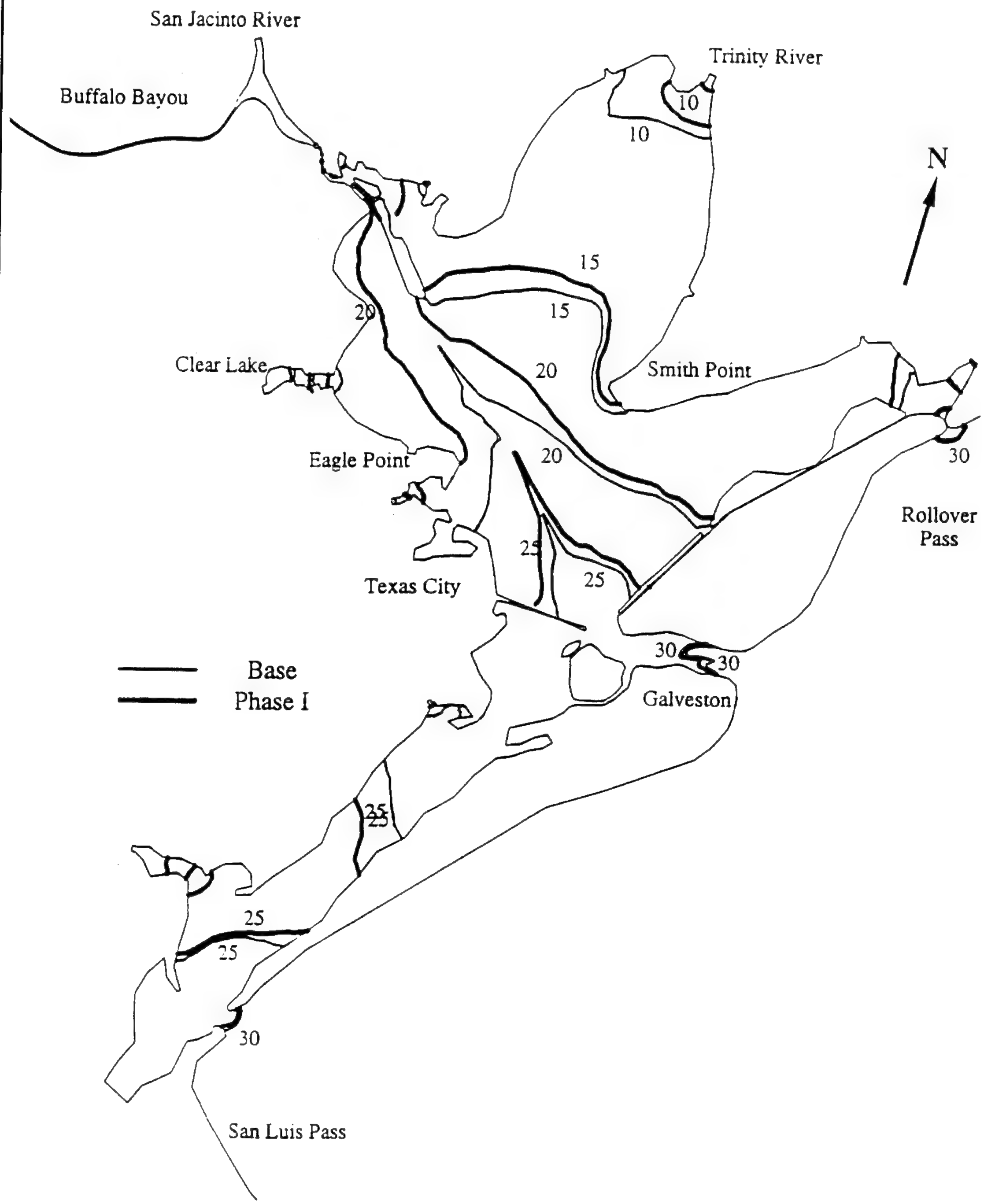
SALINITY CONTOURS, PPT
JUNE 1999, PHASE I
LOW FLOW, BOTTOM

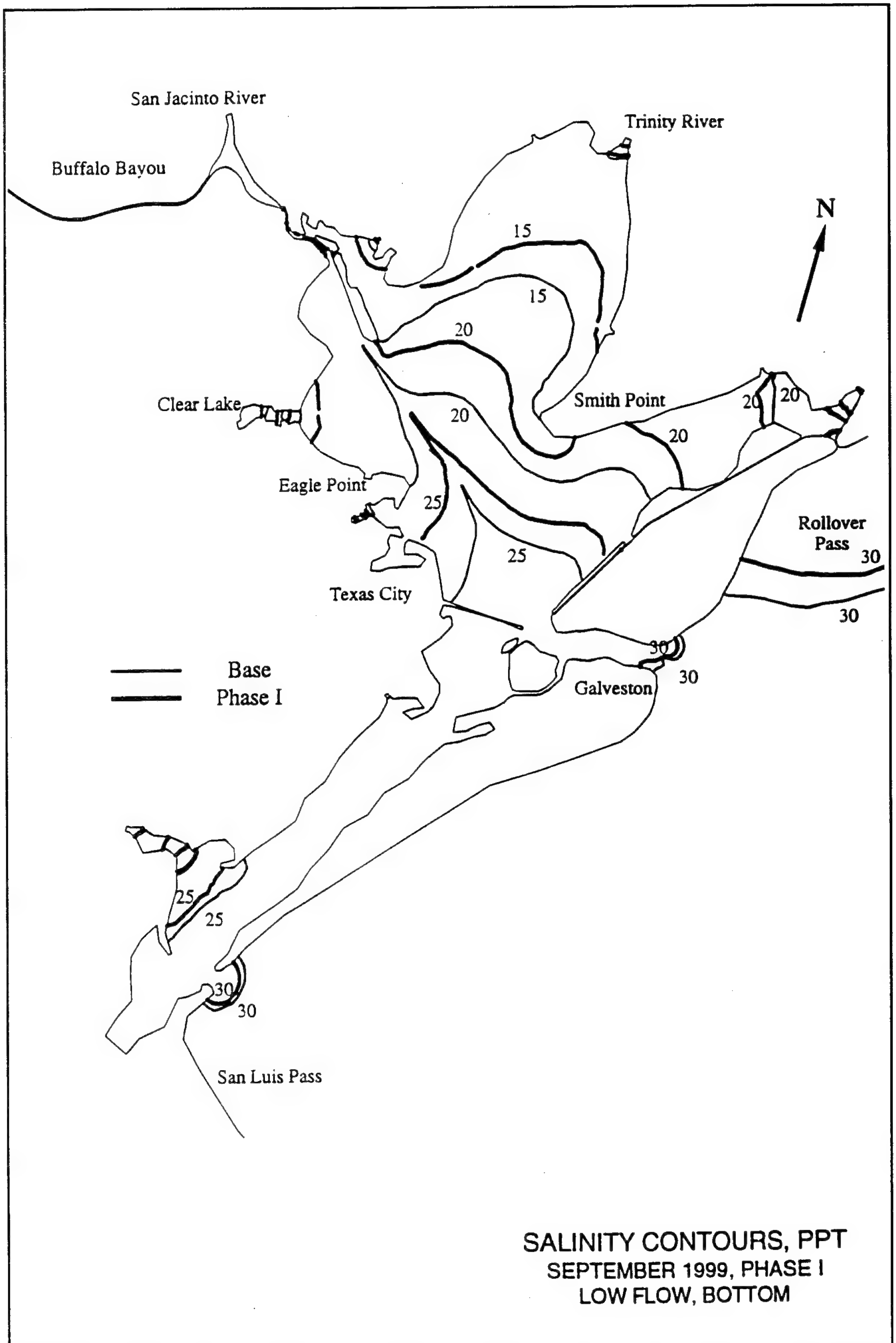


SALINITY CONTOURS, PPT
JULY 1999, PHASE I
LOW FLOW, BOTTOM



SALINITY CONTOURS, PPT
AUGUST 1999, PHASE I
LOW FLOW, BOTTOM

Plate 316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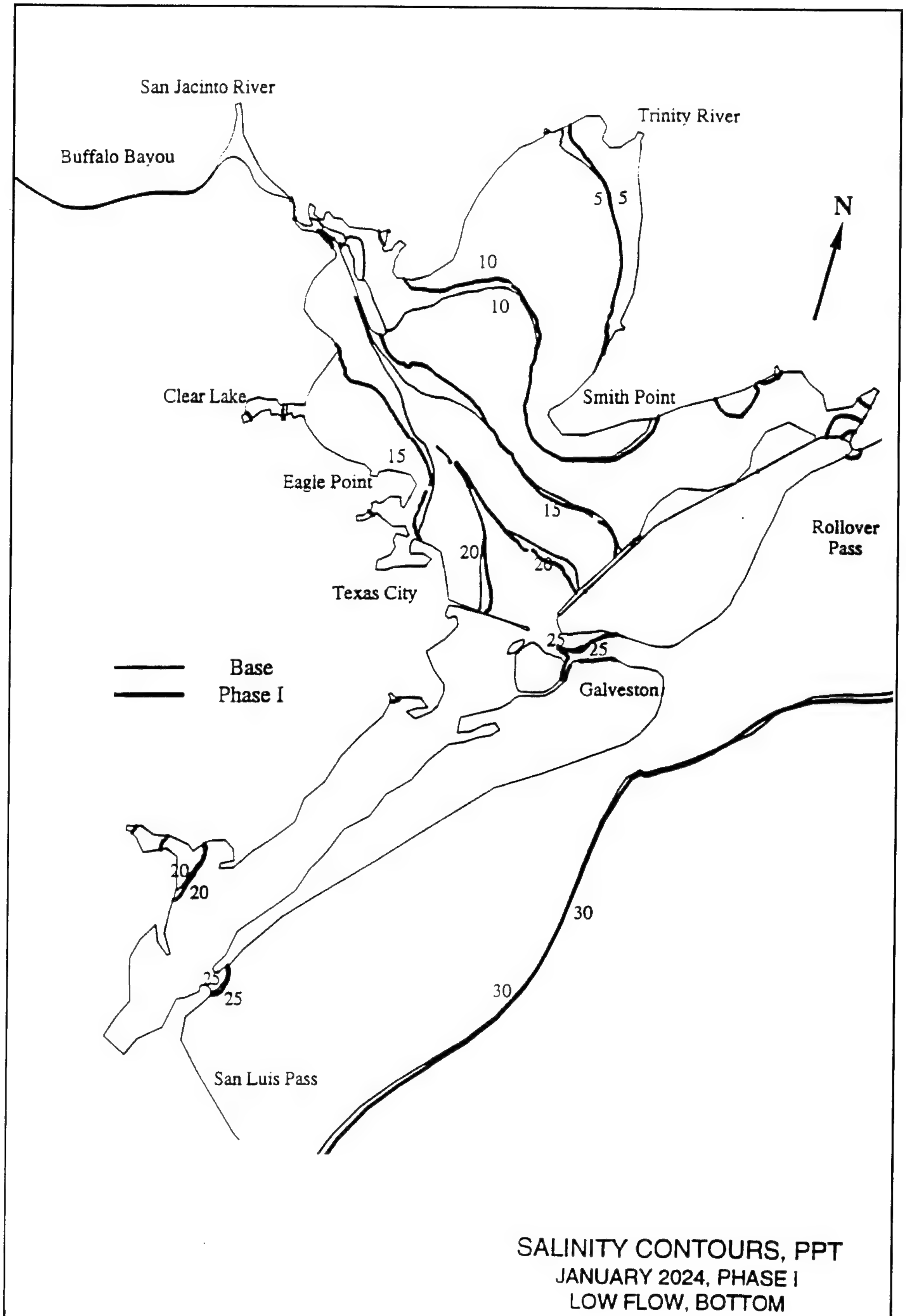
SALINITY CONTOURS, PPT
SEPTEMBER 1999, PHASE I
LOW FLOW, BOTTOM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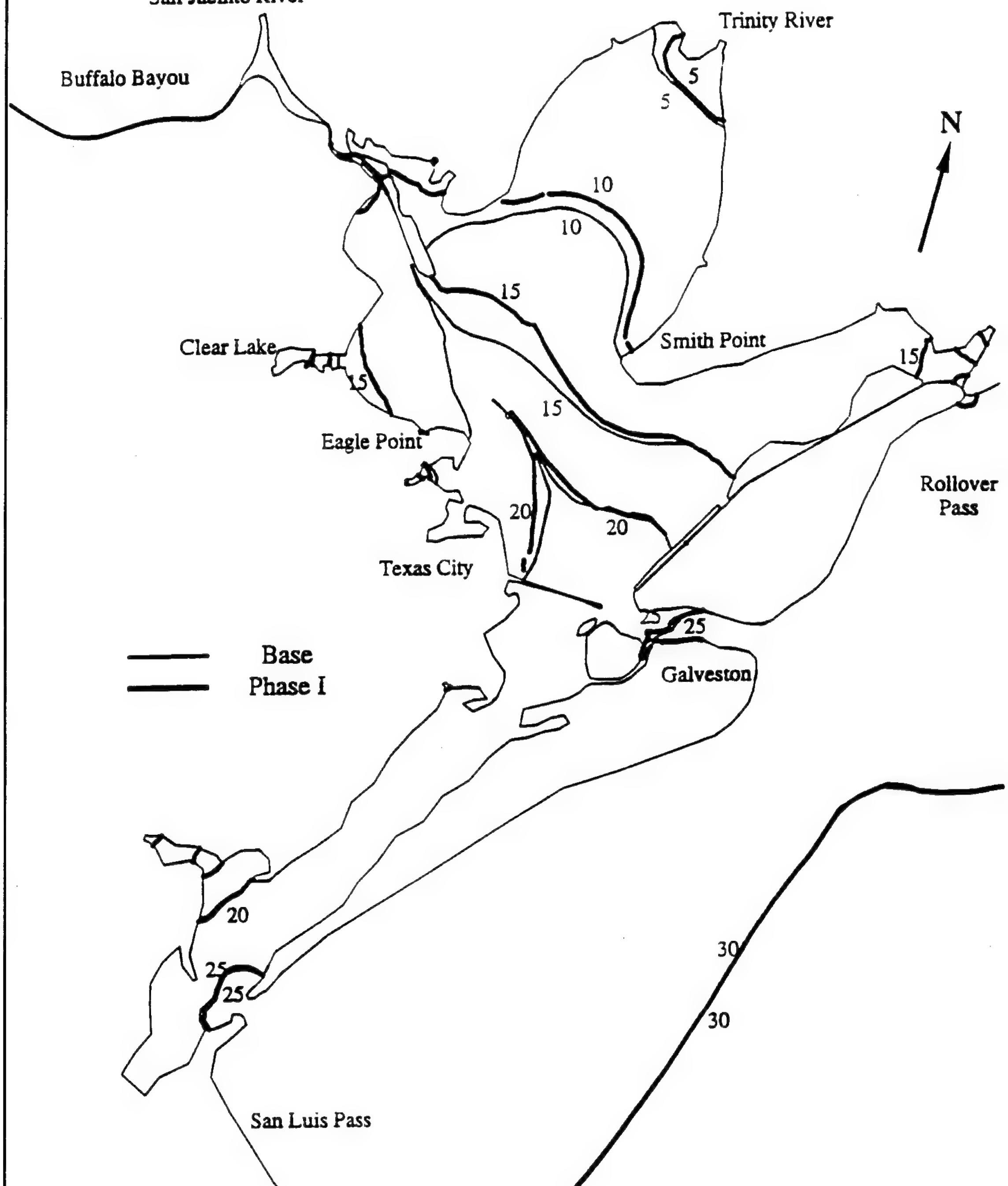
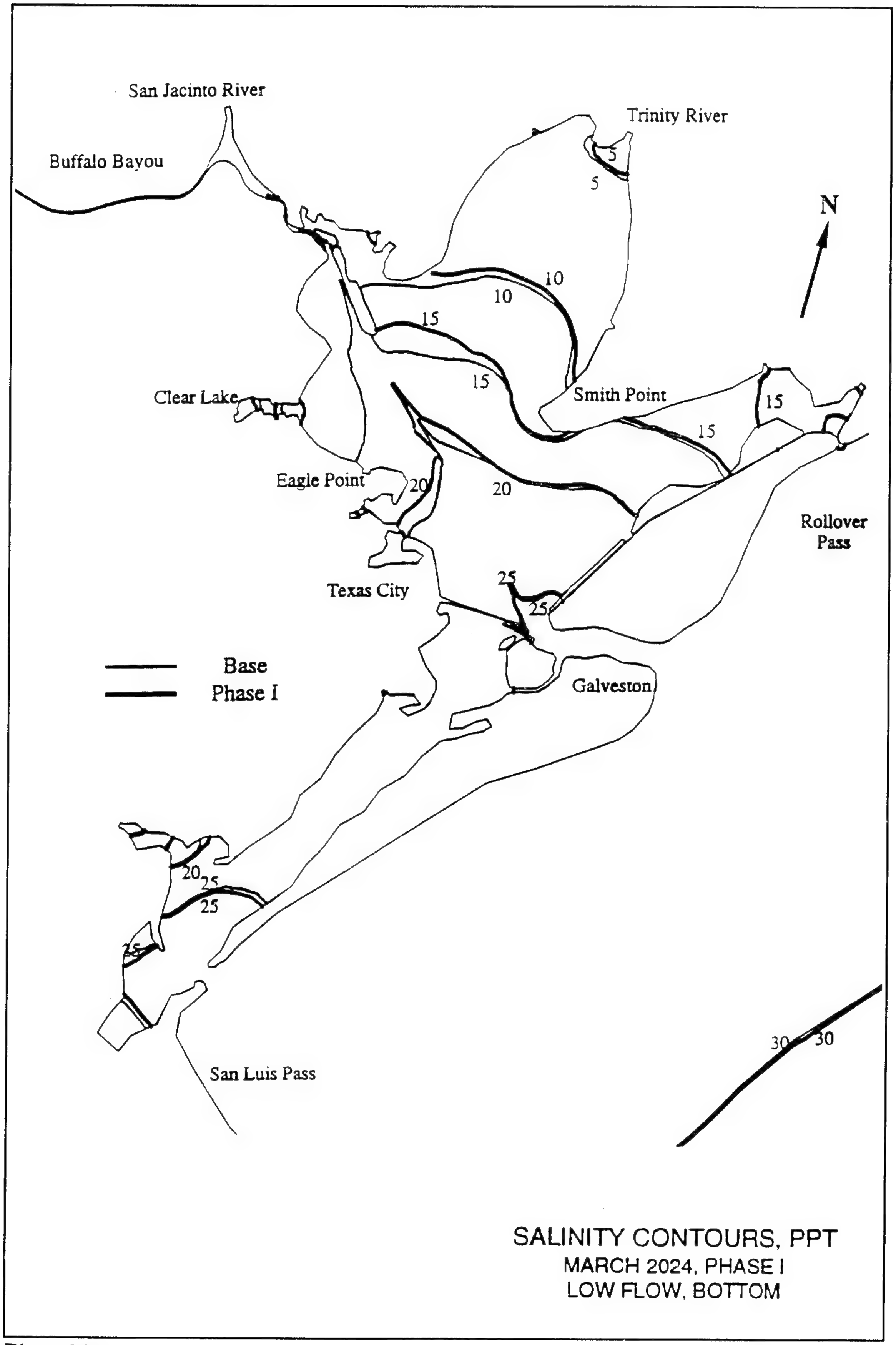
SALINITY CONTOURS, PPT
JANUARY 2024, PHASE I
LOW FLOW, BOTTOM

Plate 318



SALINITY CONTOURS, PPT
FEBRUARY 2024, PHASE I
LOW FLOW, BOTTOM


San Jacinto River
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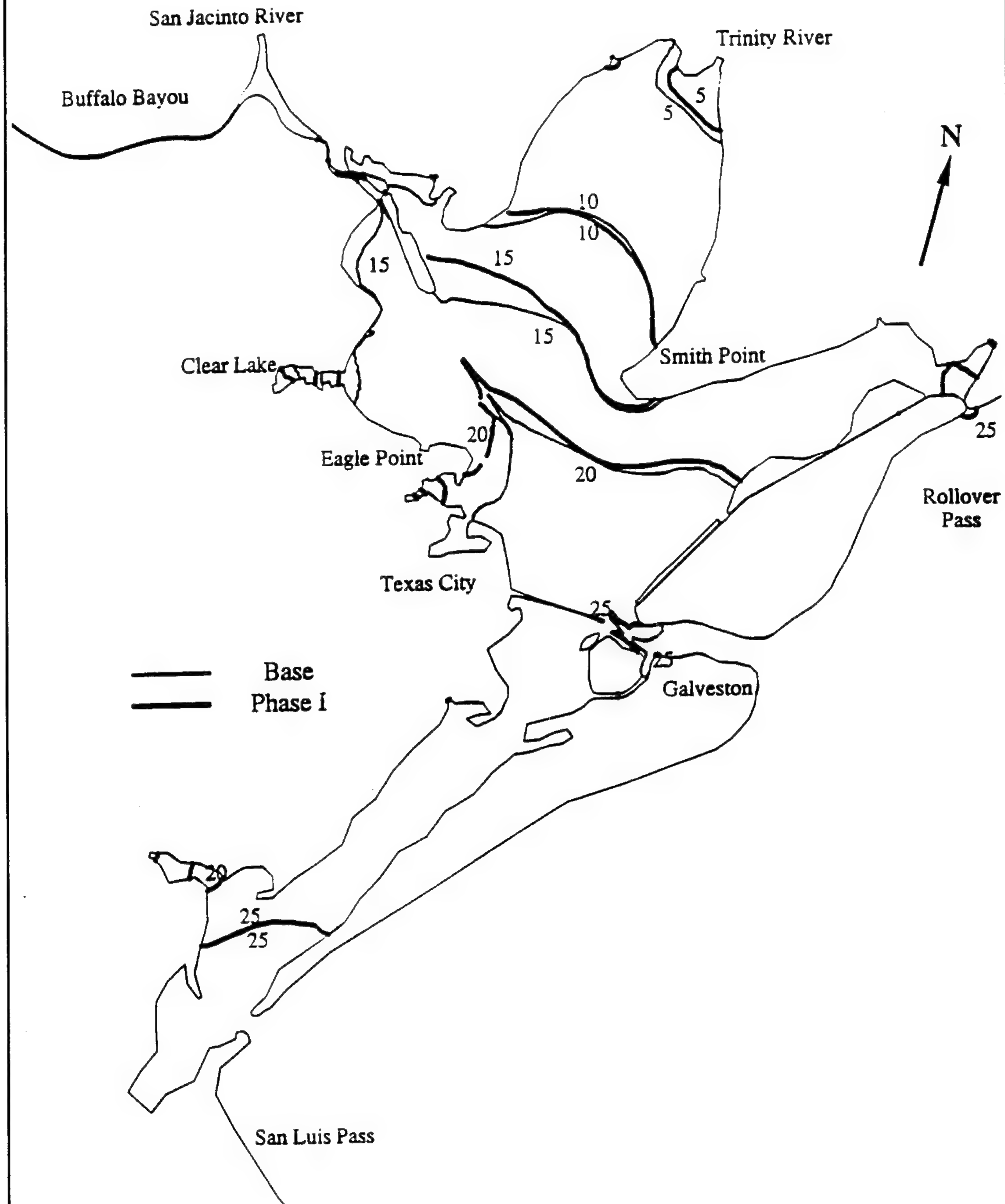
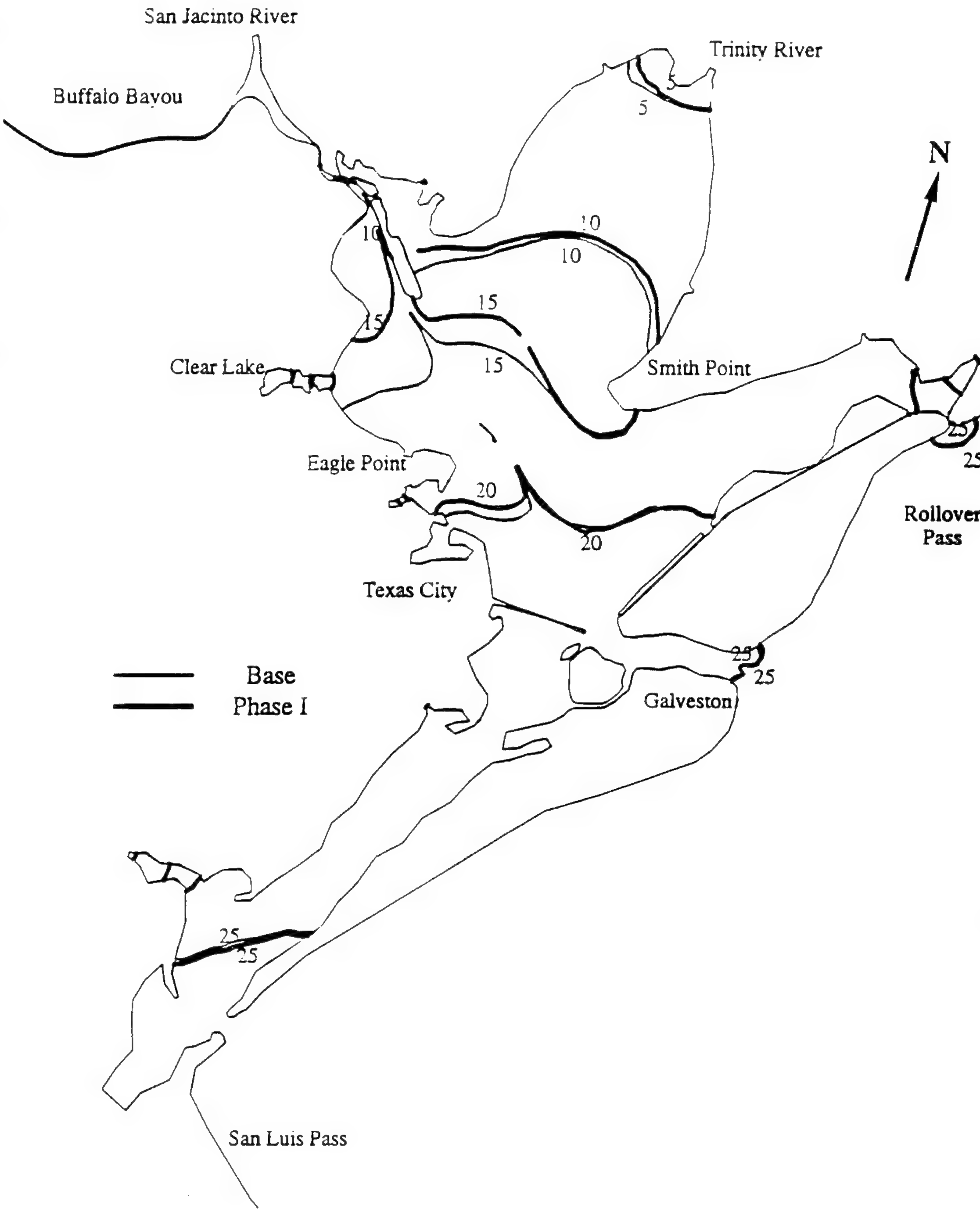
SALINITY CONTOURS, PPT
MARCH 2024, PHASE I
LOW FLOW, BOTTOM

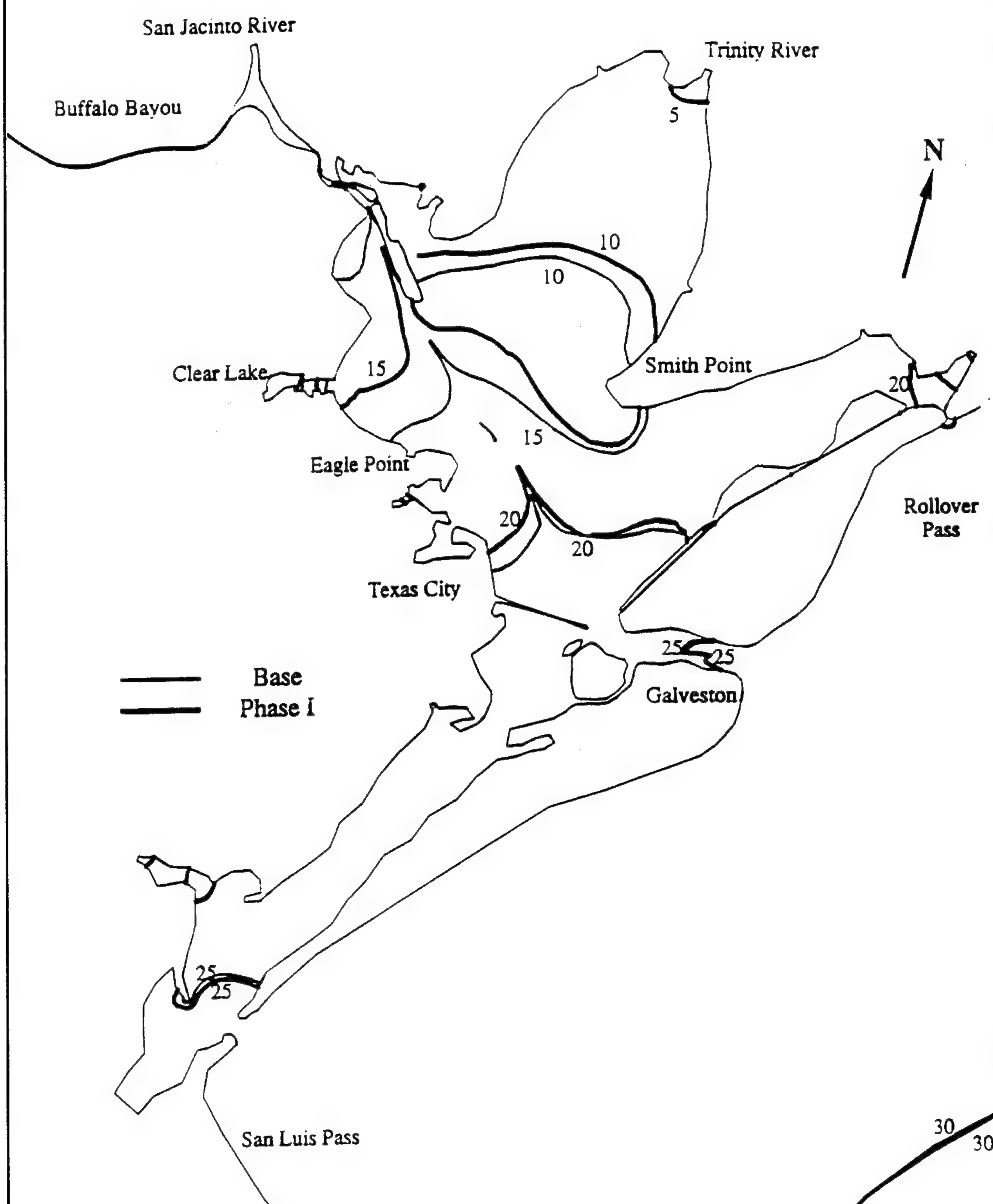
Plate 320



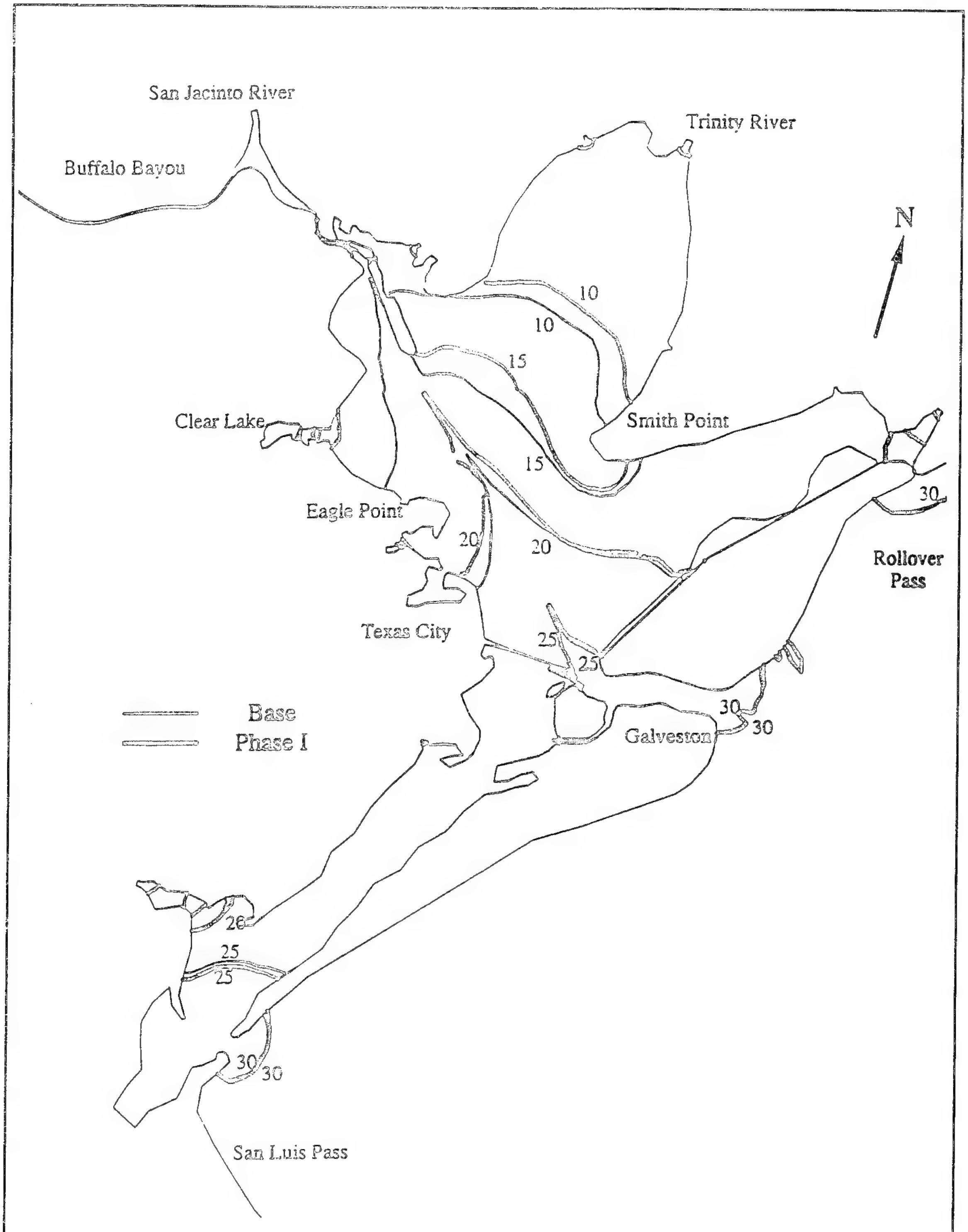
SALINITY CONTOURS, PPT
APRIL 2024, PHASE I
LOW FLOW, BOTTOM



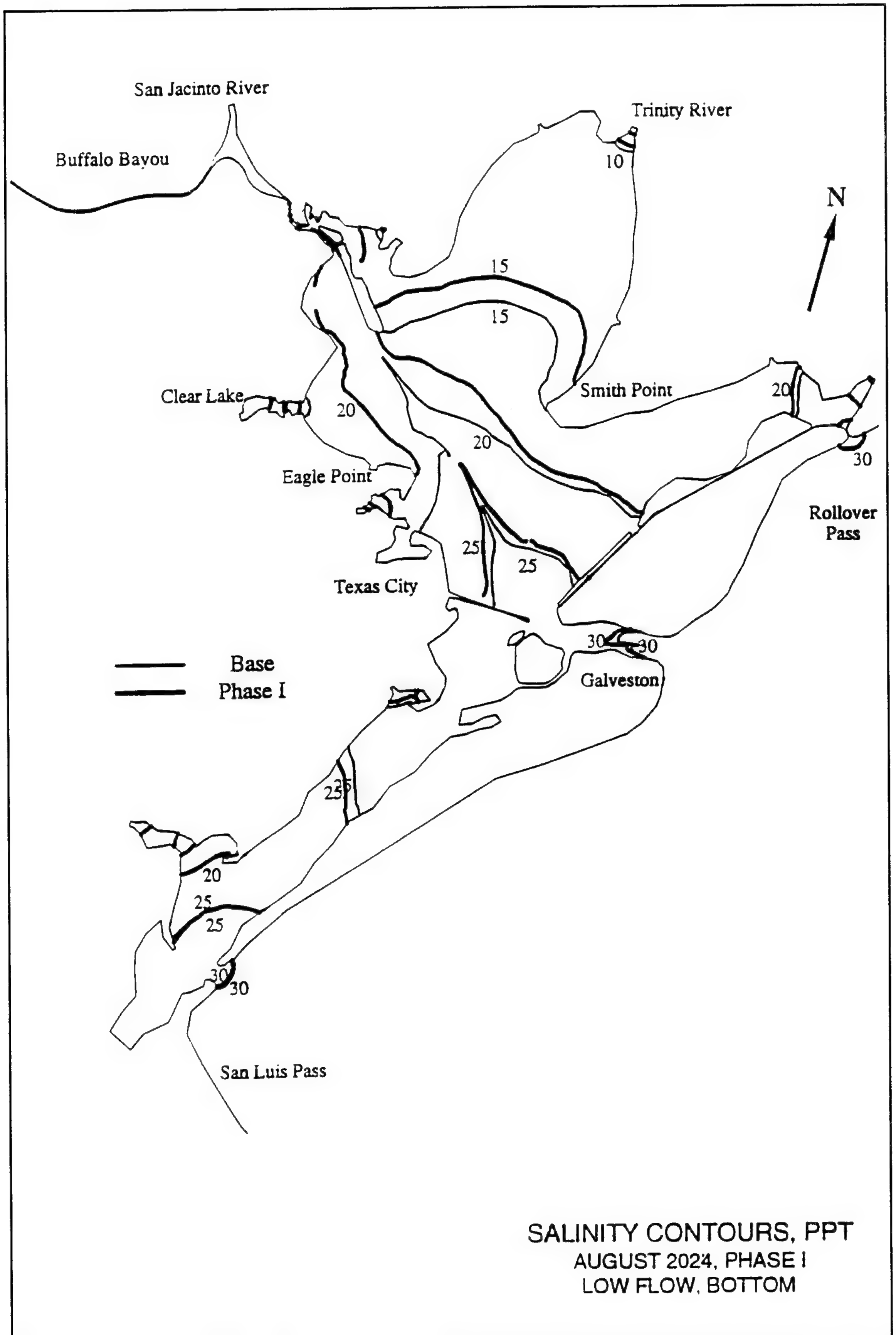
SALINITY CONTOURS, PPT
MAY 2024, PHASE I
LOW FLOW, BOTTOM



SALINITY CONTOURS, PPT
JUNE 2024, PHASE I
LOW FLOW, BOTTOM



SALINITY CONTOURS, PPT
JULY 2024, PHASE I
LOW FLOW, BOTTOM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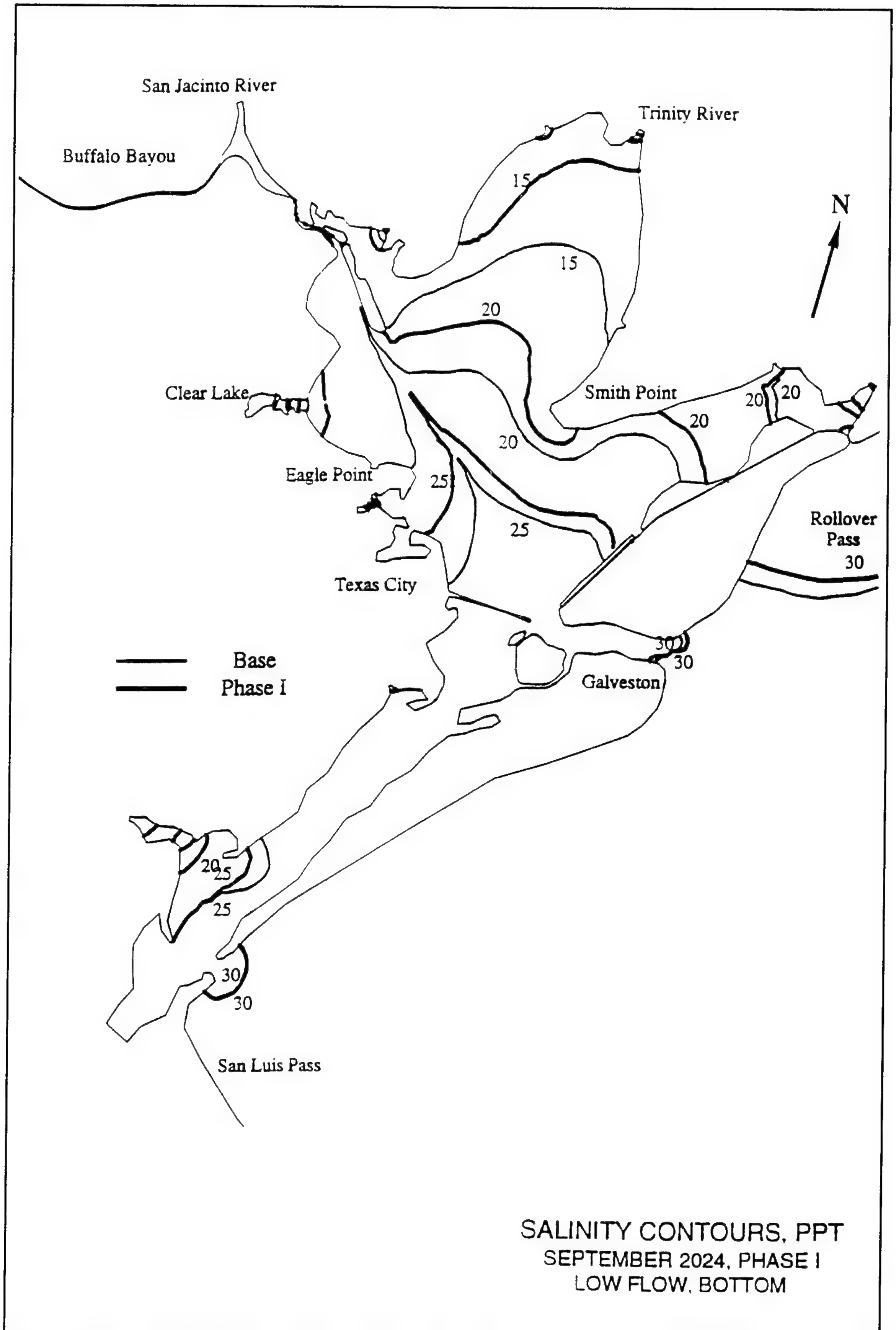
SALINITY CONTOURS, PPT
AUGUST 2024, PHASE I
LOW FLOW, BOTTOM



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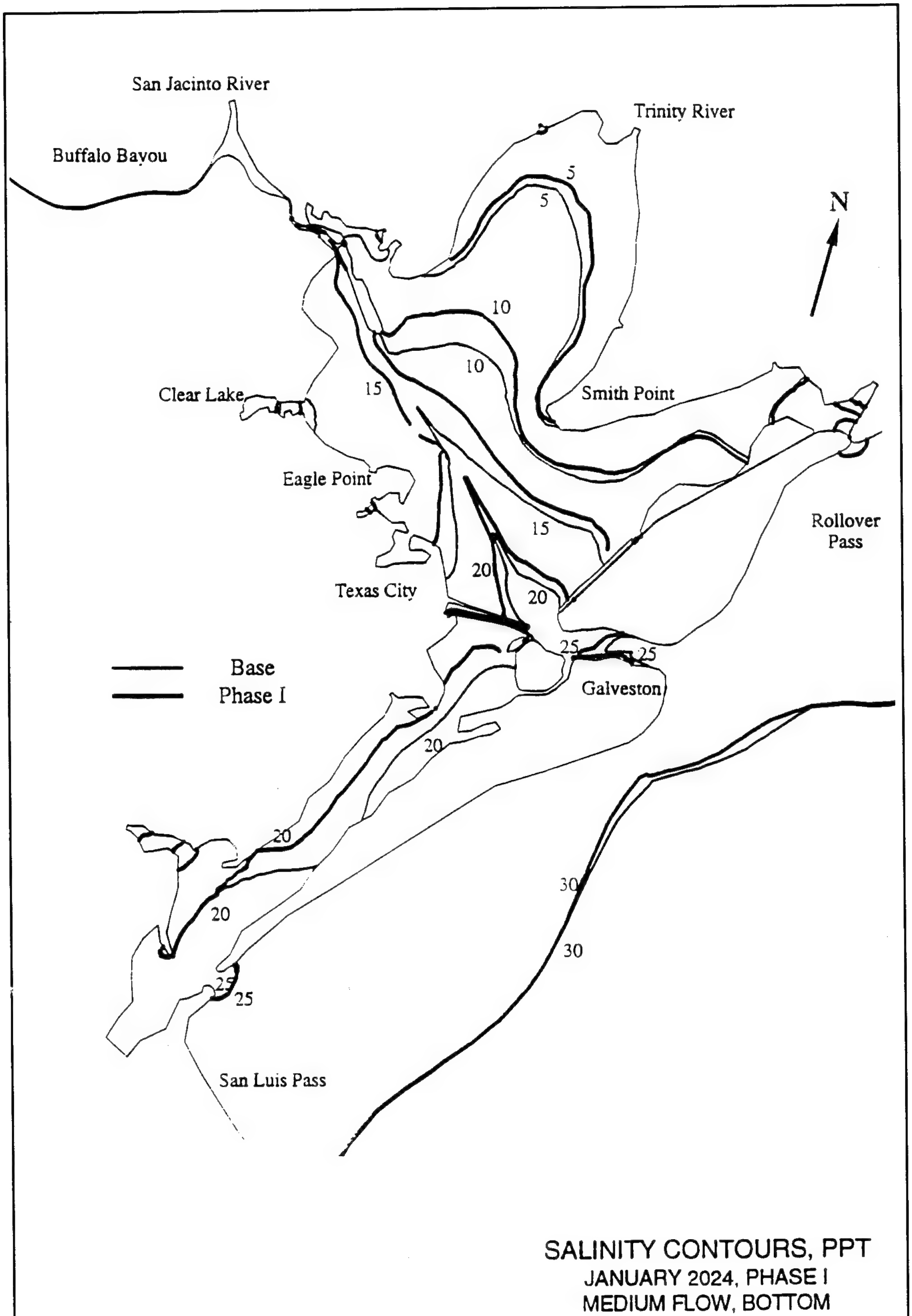
SALINITY CONTOURS, PPT
SEPTEMBER 2024, PHASE I
LOW FLOW, BOTTOM


San Jacinto River
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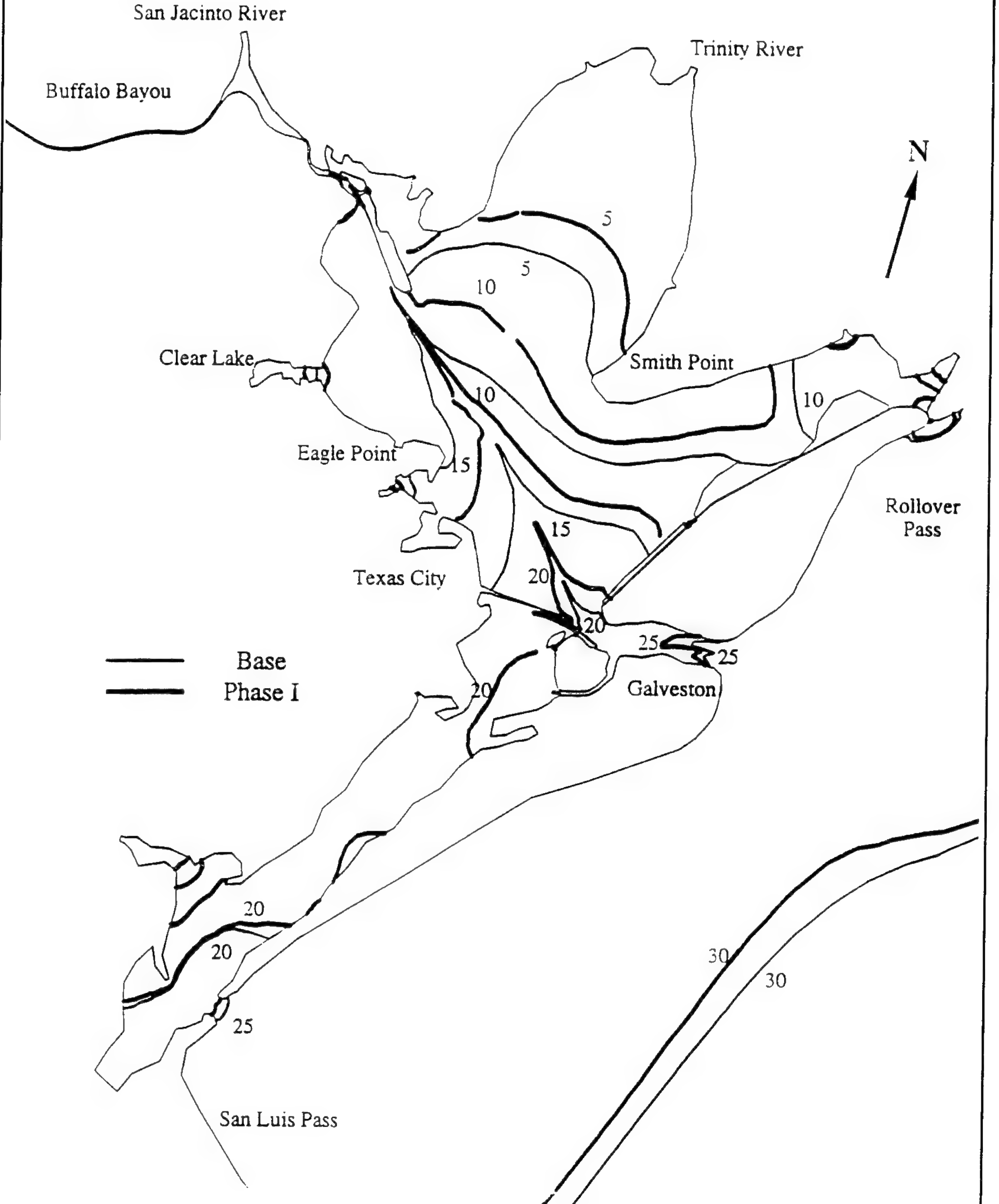
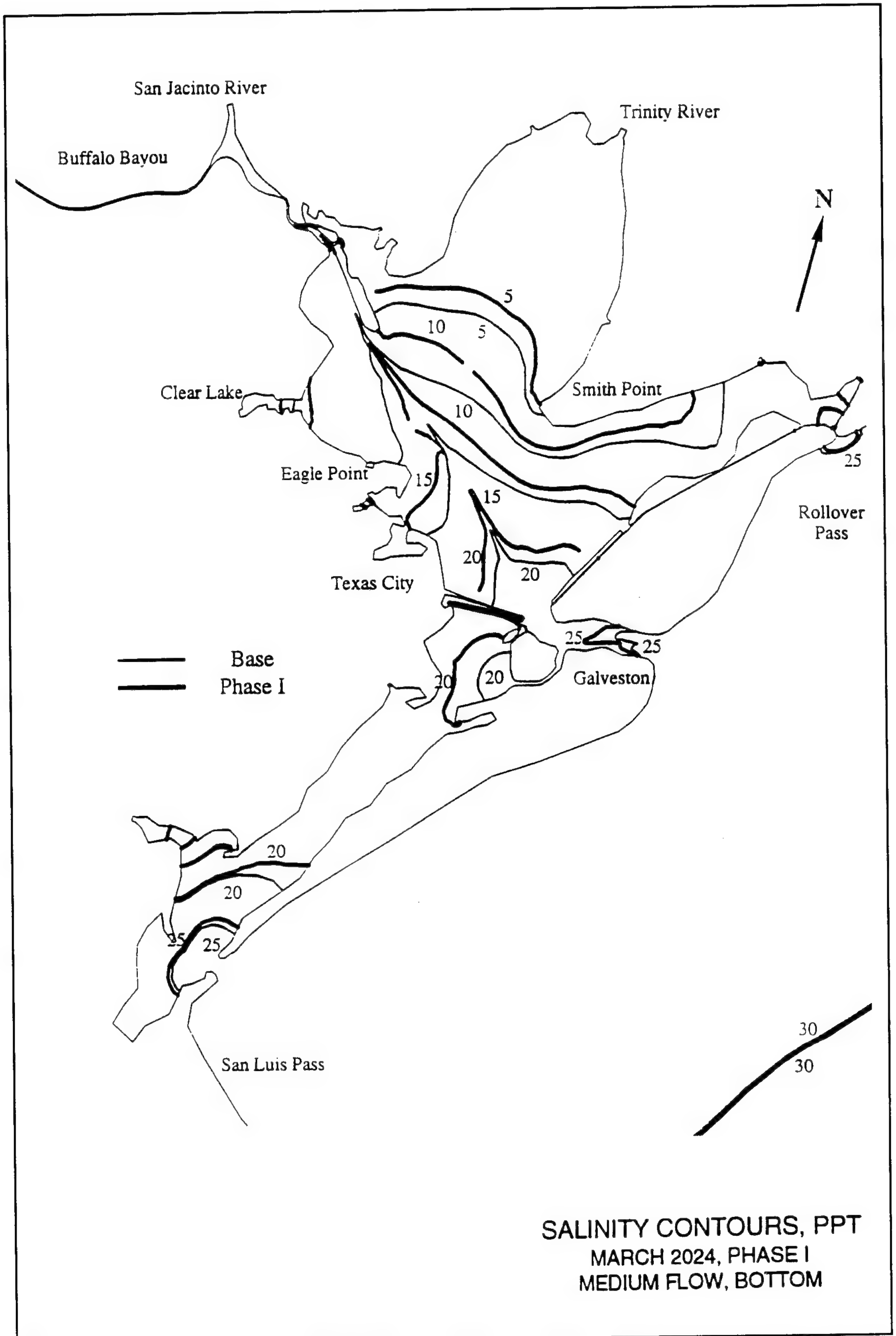
SALINITY CONTOURS, PPT
JANUARY 2024, PHASE I
MEDIUM FLOW, BOTTOM



SALINITY CONTOURS, PPT
FEBRUARY 2024, PHASE I
MEDIUM FLOW, BOTTOM


San Jacinto River
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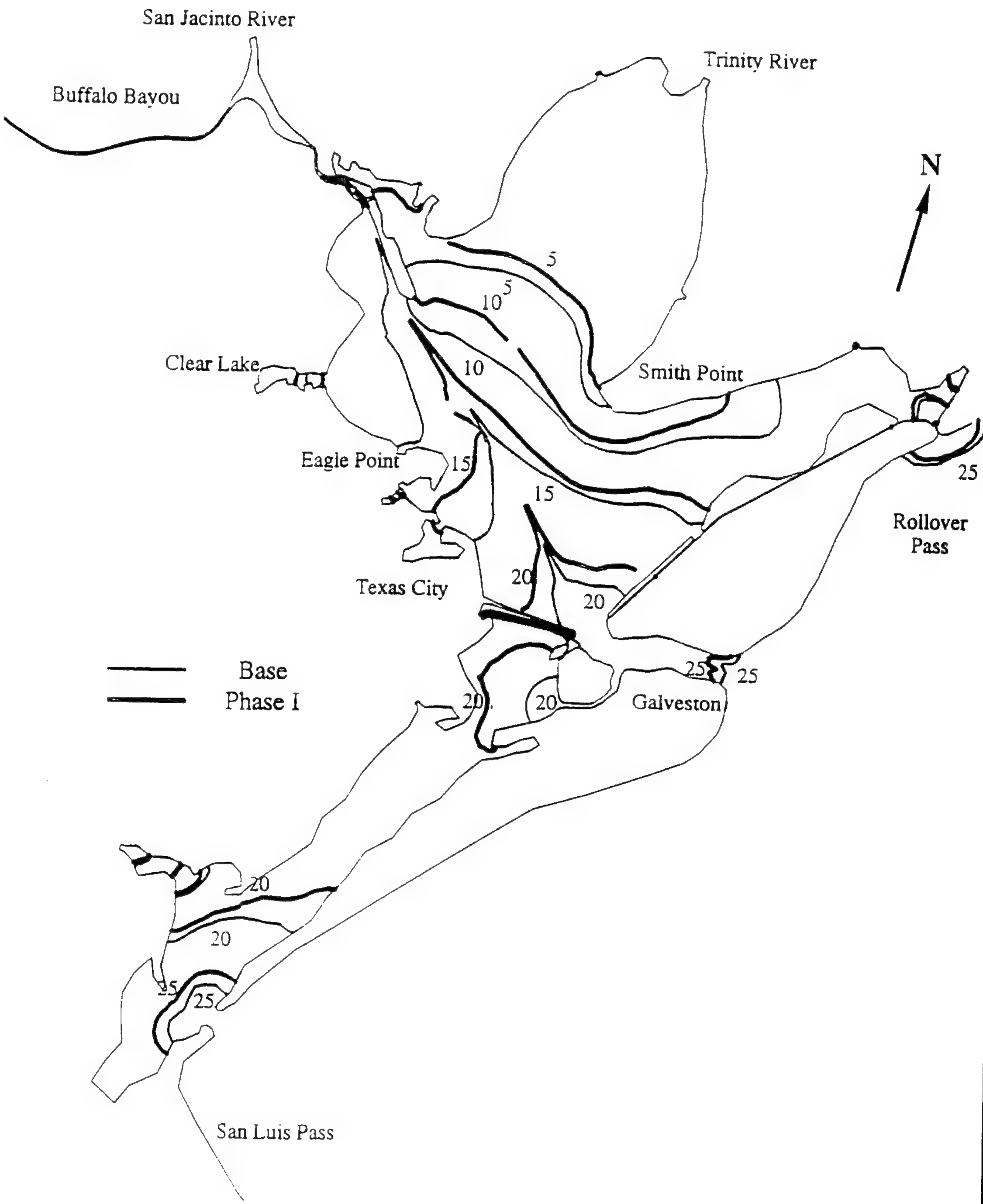
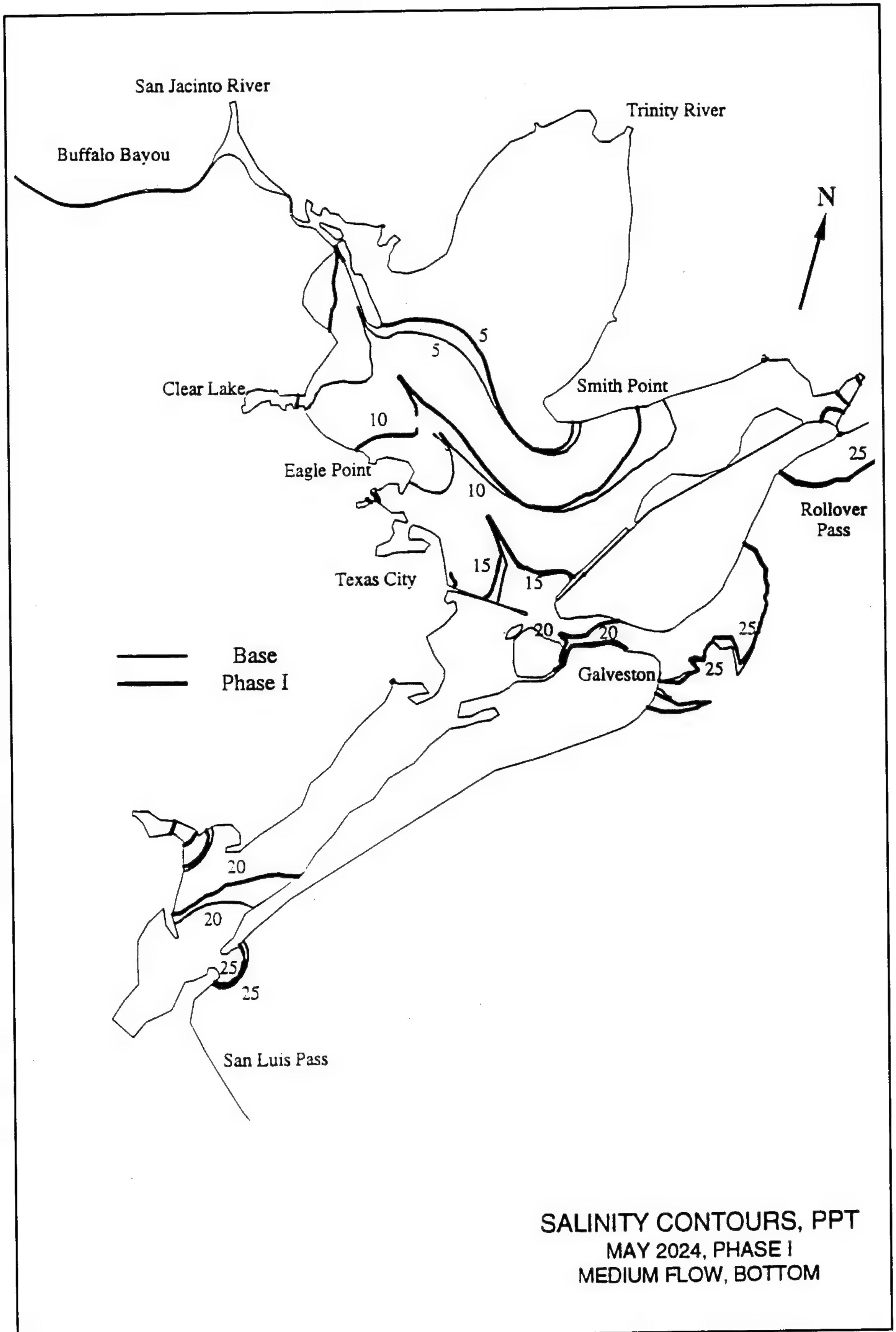
SALINITY CONTOURS, PPT
MARCH 2024, PHASE I
MEDIUM FLOW, BOTTOM



SALINITY CONTOURS, PPT
APRIL 2024, PHASE I
MEDIUM FLOW, BOTTOM


San Jacinto River
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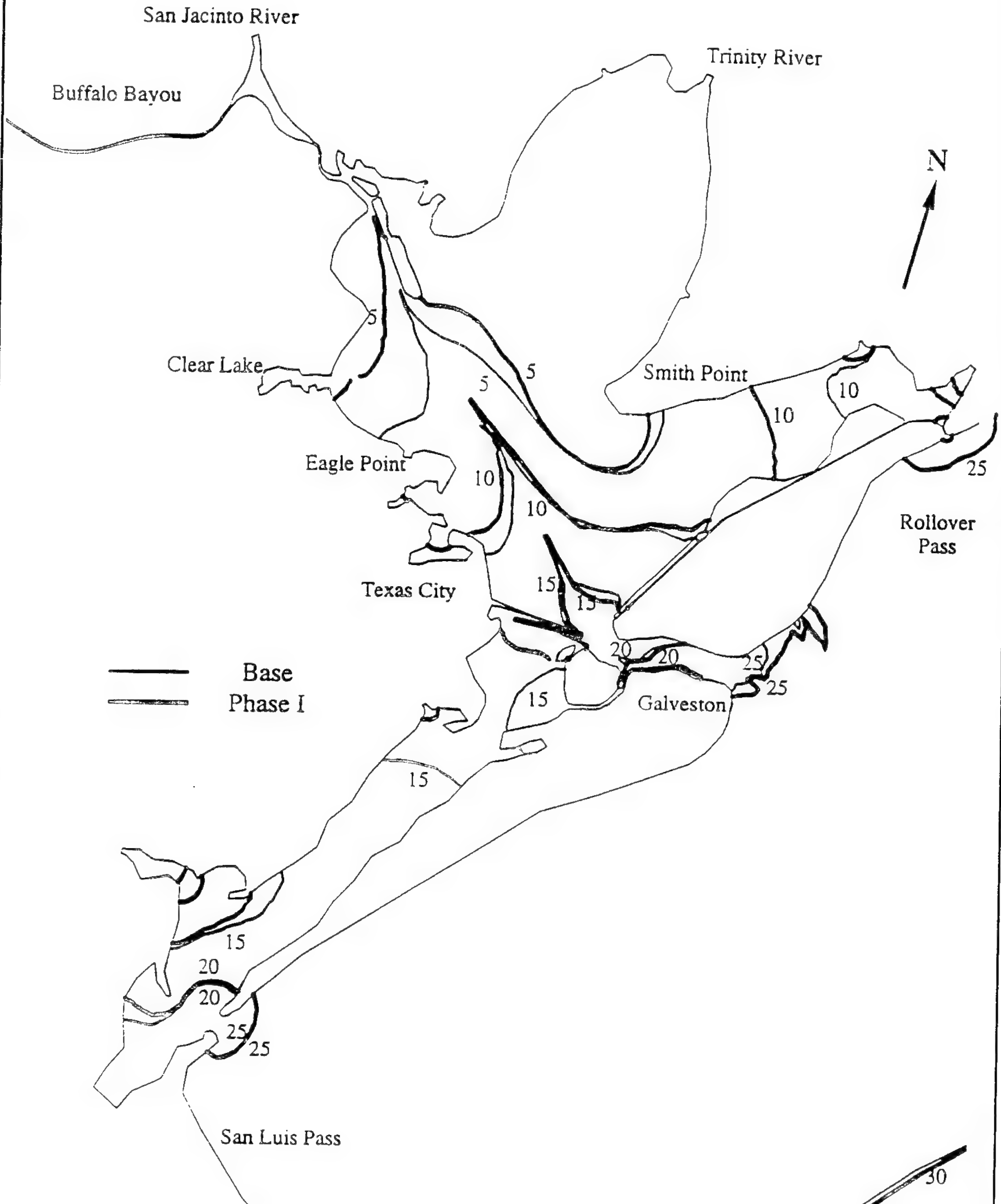
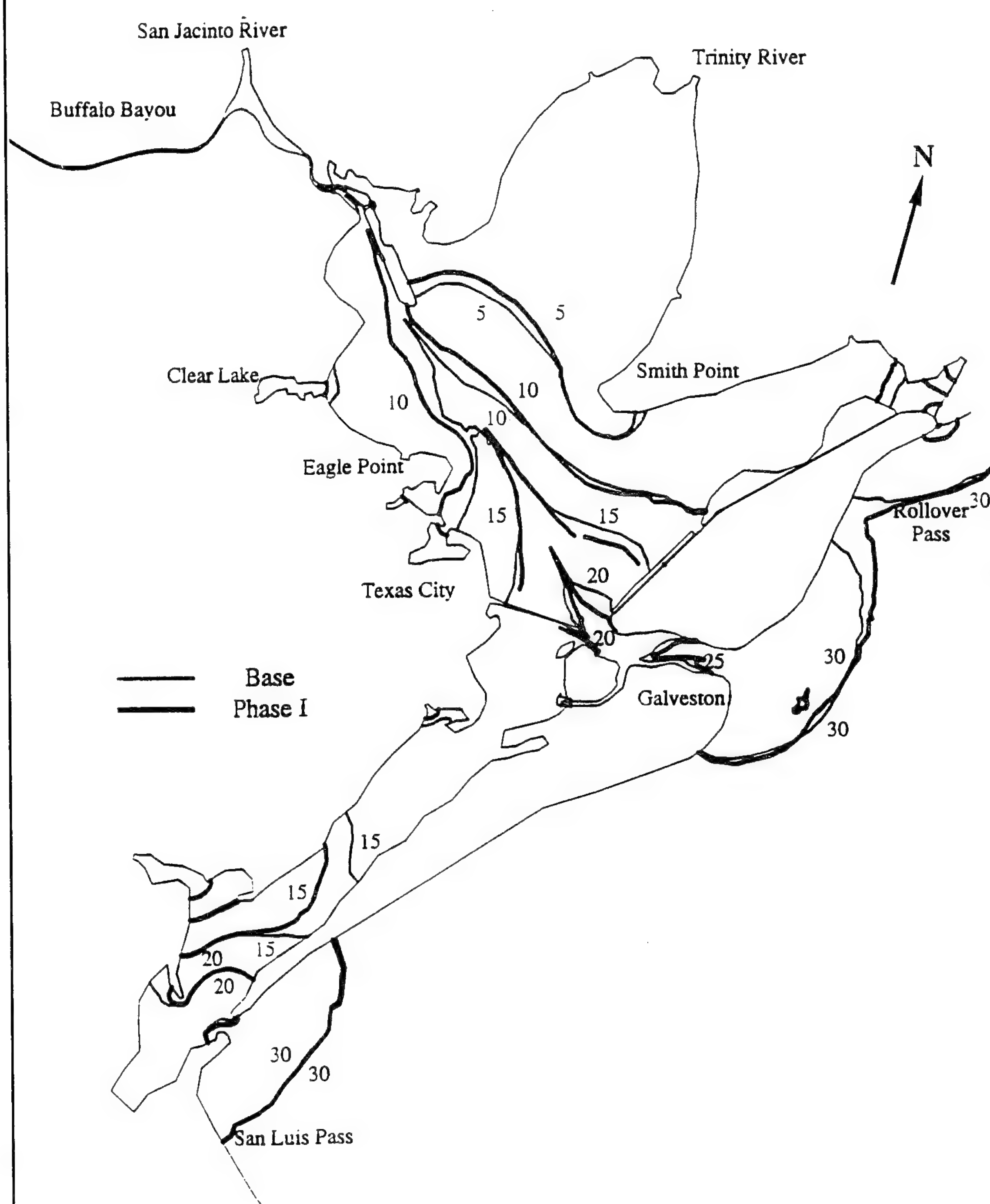
SALINITY CONTOURS, PPT
MAY 2024, PHASE I
MEDIUM FLOW, BOTTOM

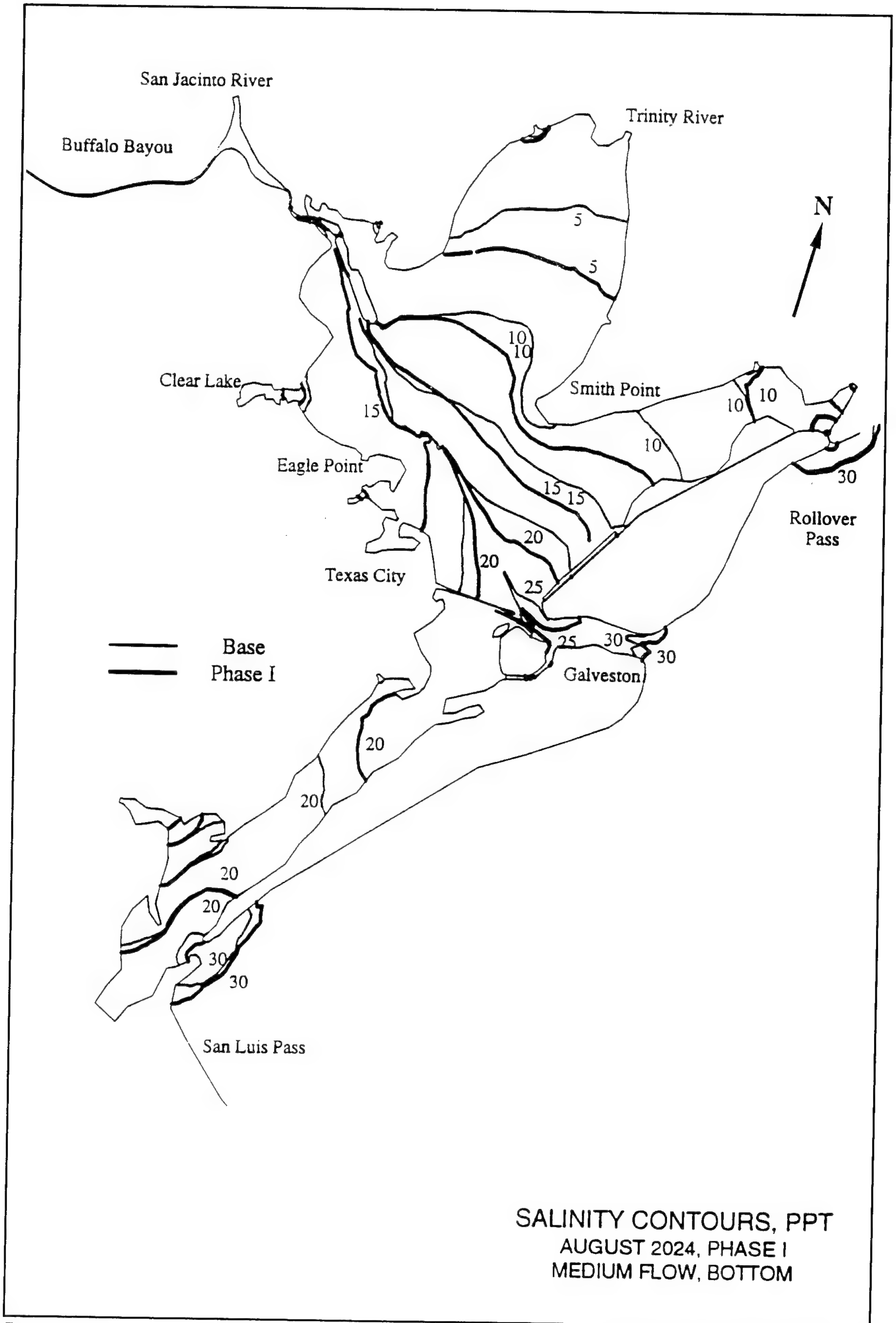


SALINITY CONTOURS, PPT
JUNE 2024, PHASE I
MEDIUM FLOW, BOTTOM

Plate 332



SALINITY CONTOURS, PPT
JULY 2024, PHASE I
MEDIUM FLOW, BOTTOM


San Jacinto River
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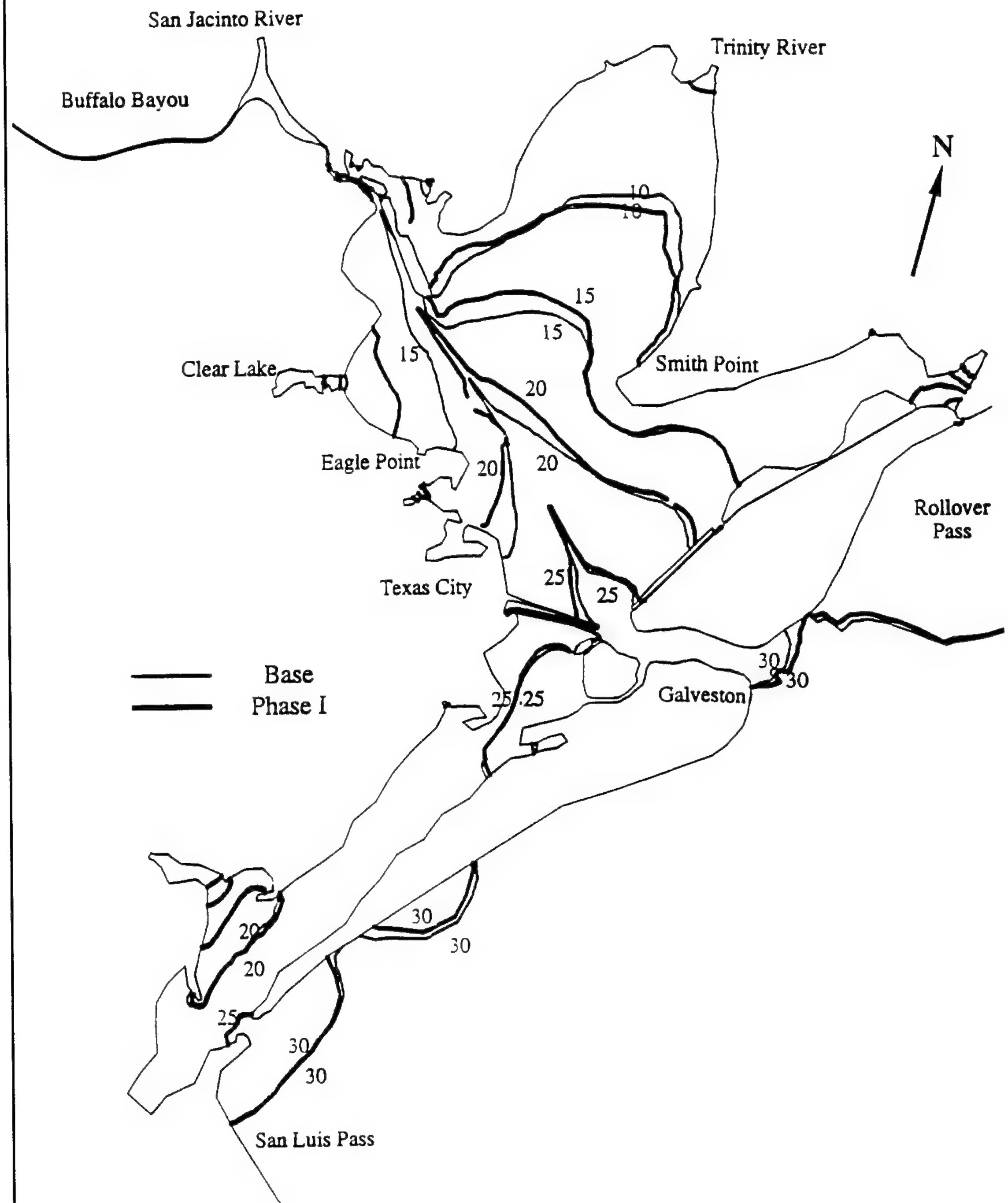
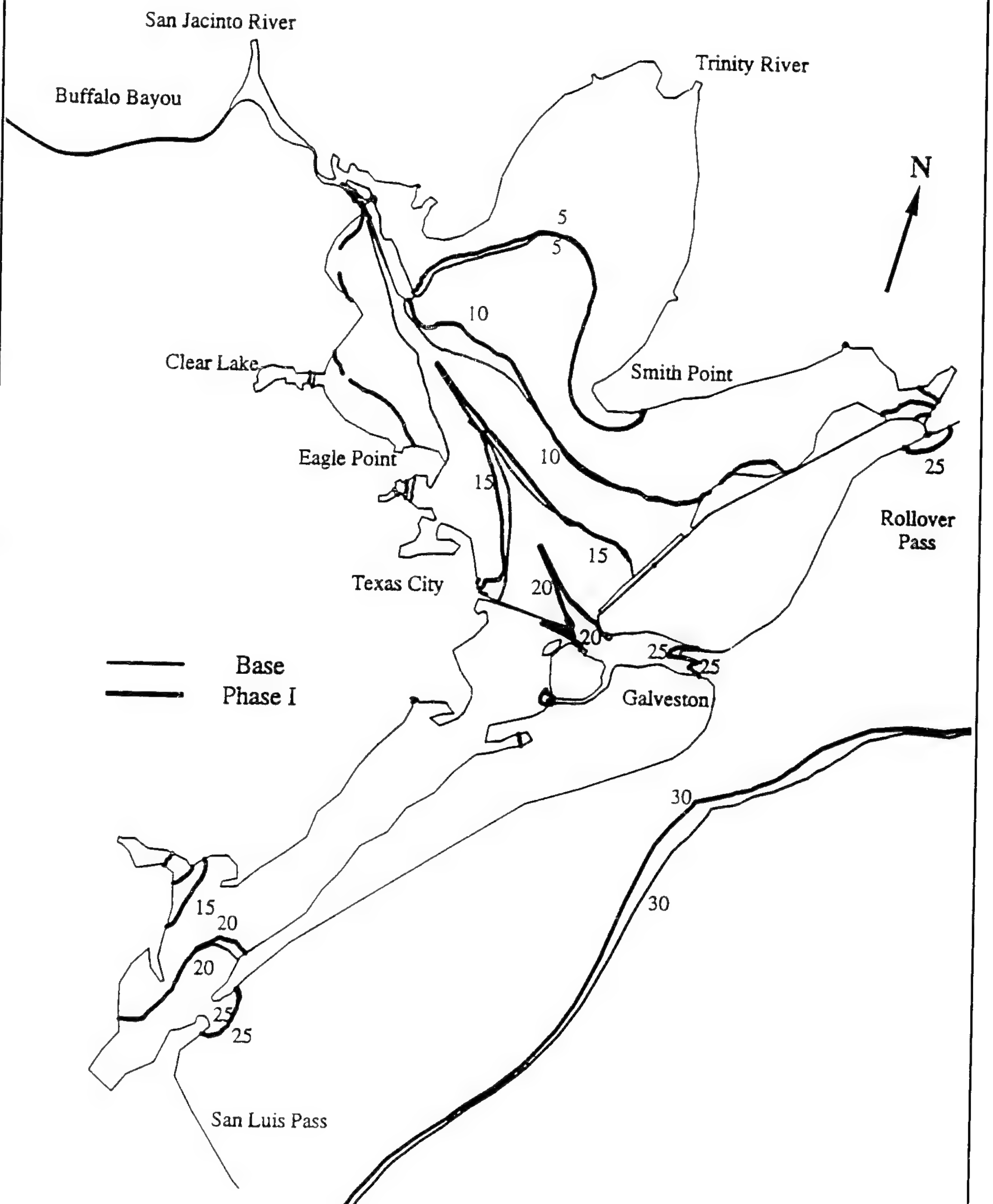
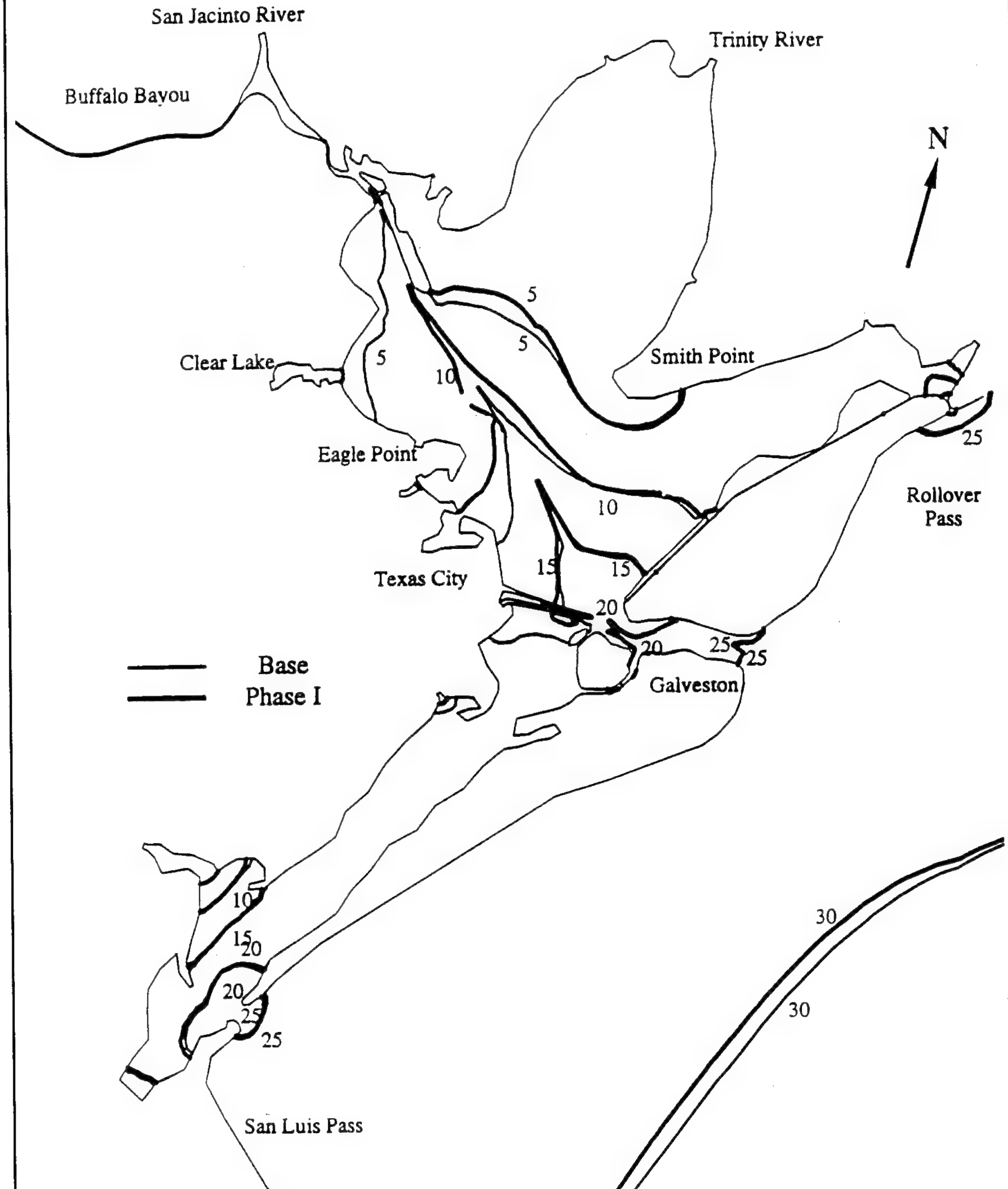
SALINITY CONTOURS, PPT
AUGUST 2024, PHASE I
MEDIUM FLOW, BOTTOM



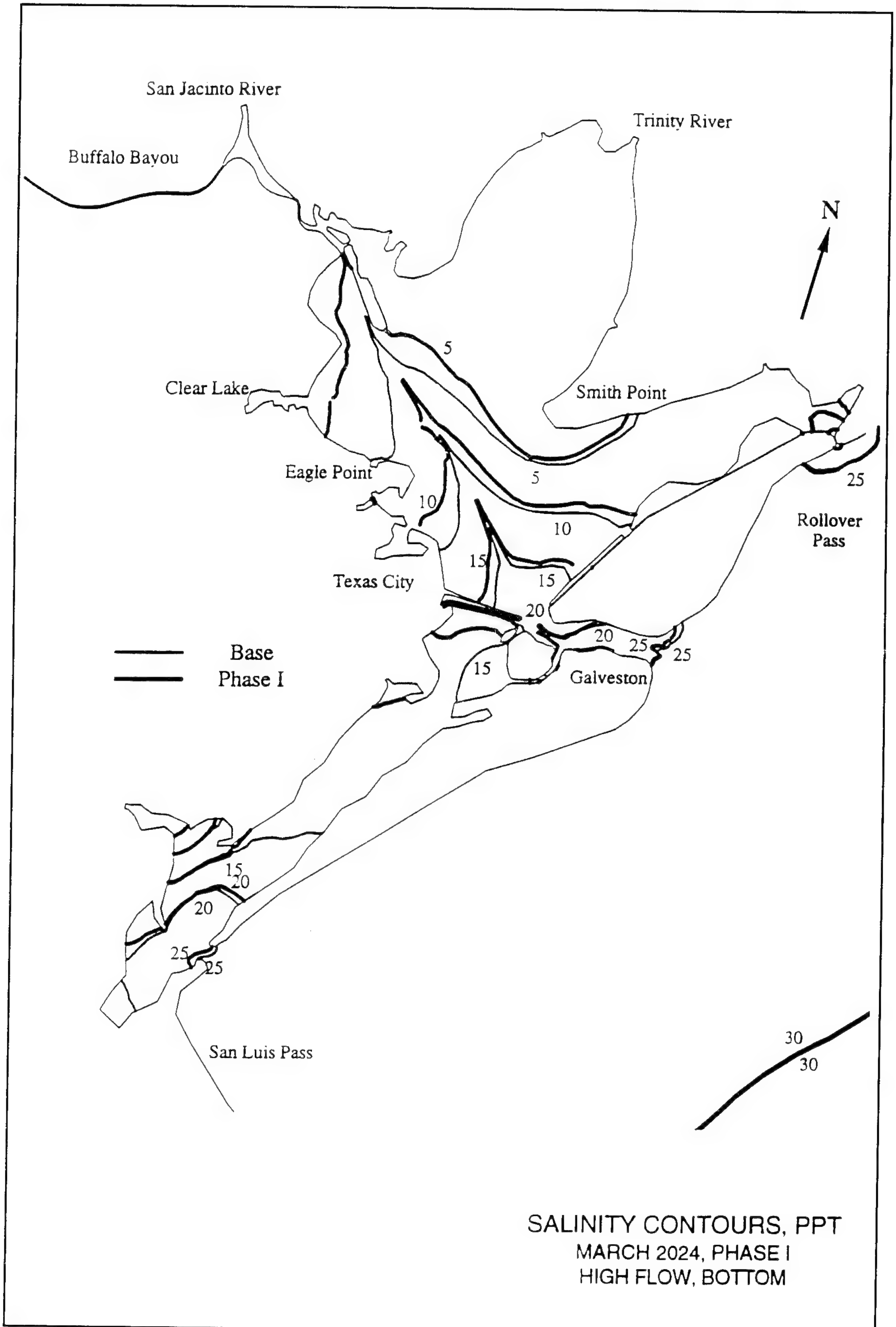
SALINITY CONTOURS, PPT
SEPTEMBER 2024, PHASE I
MEDIUM FLOW, BOTTOM



SALINITY CONTOURS, PPT
JANUARY 2024, PHASE I
HIGH FLOW, BOTTOM



SALINITY CONTOURS, PPT
FEBRUARY 2024, PHASE I
HIGH FLOW, BOTTOM


San Jacinto River
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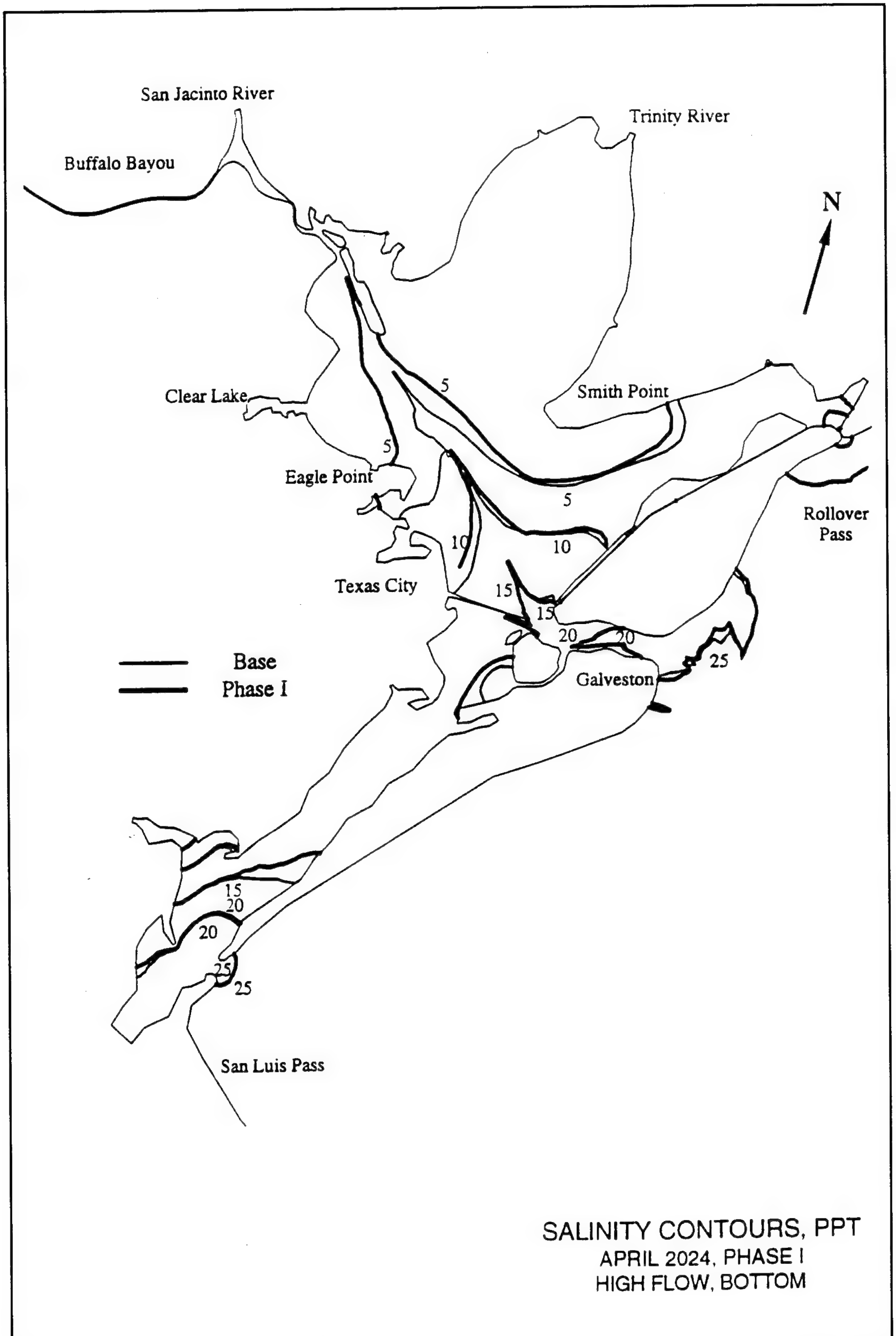
SALINITY CONTOURS, PPT
MARCH 2024, PHASE I
HIGH FLOW, BOTTOM

Plate 338


San Jacinto River
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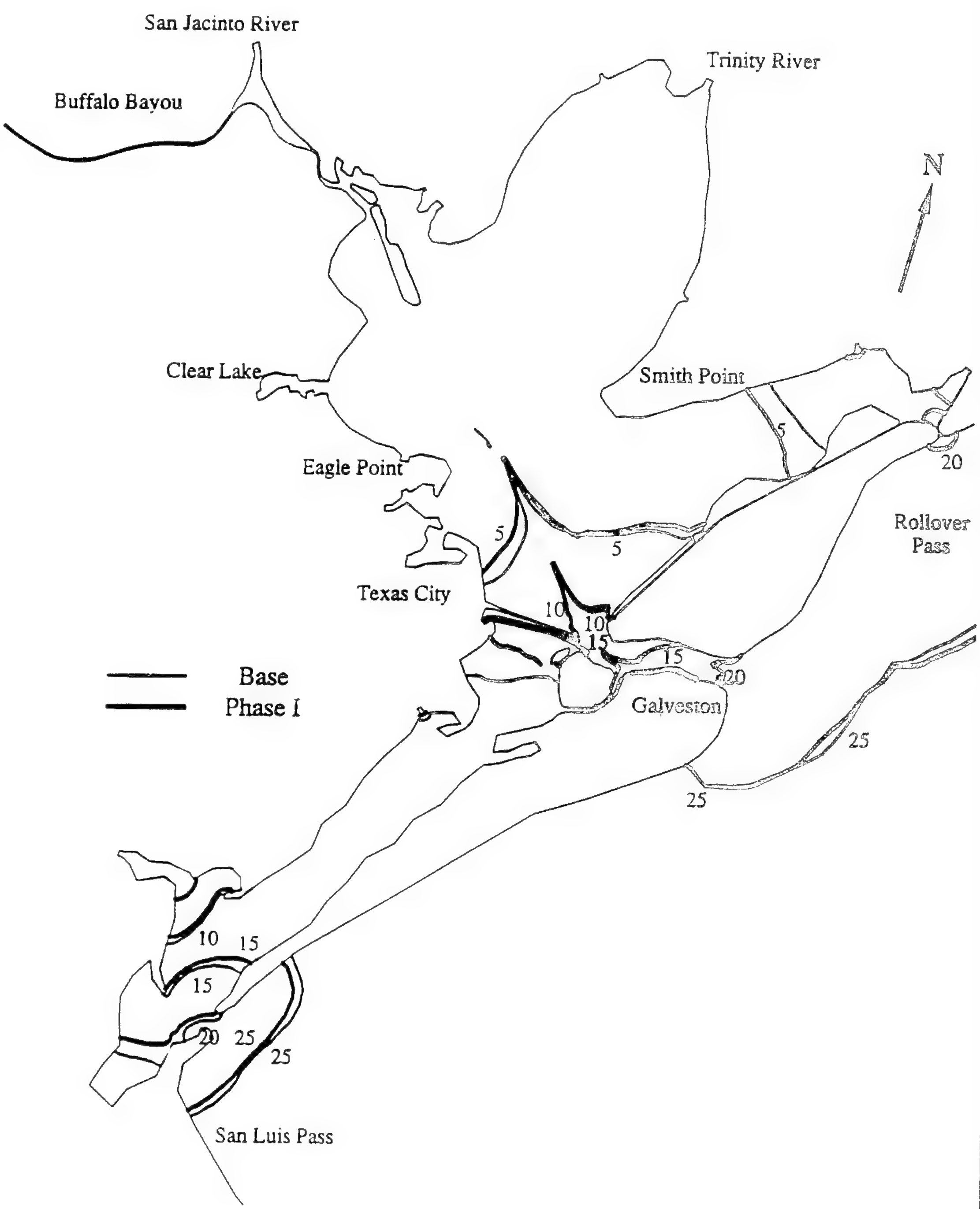
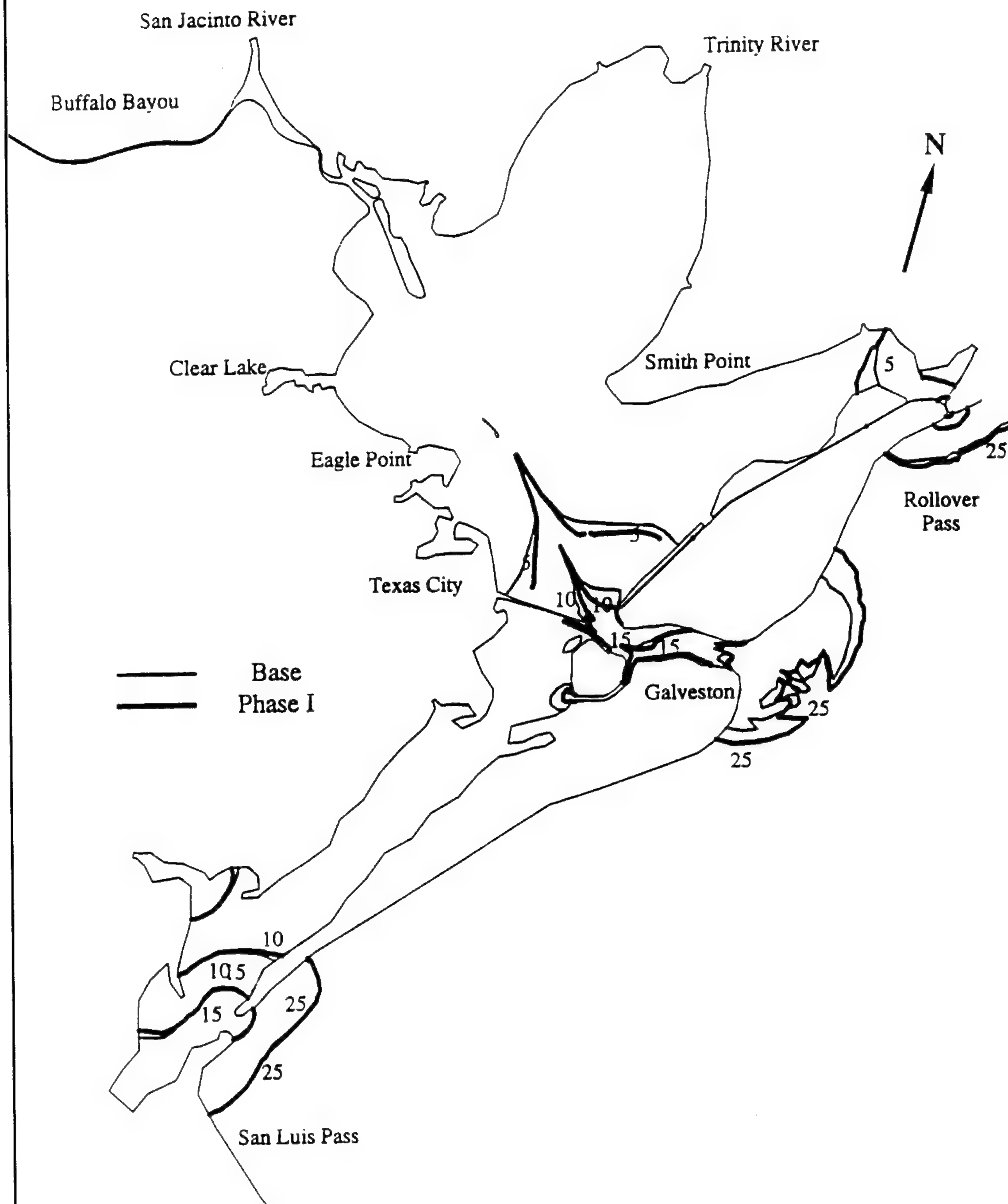
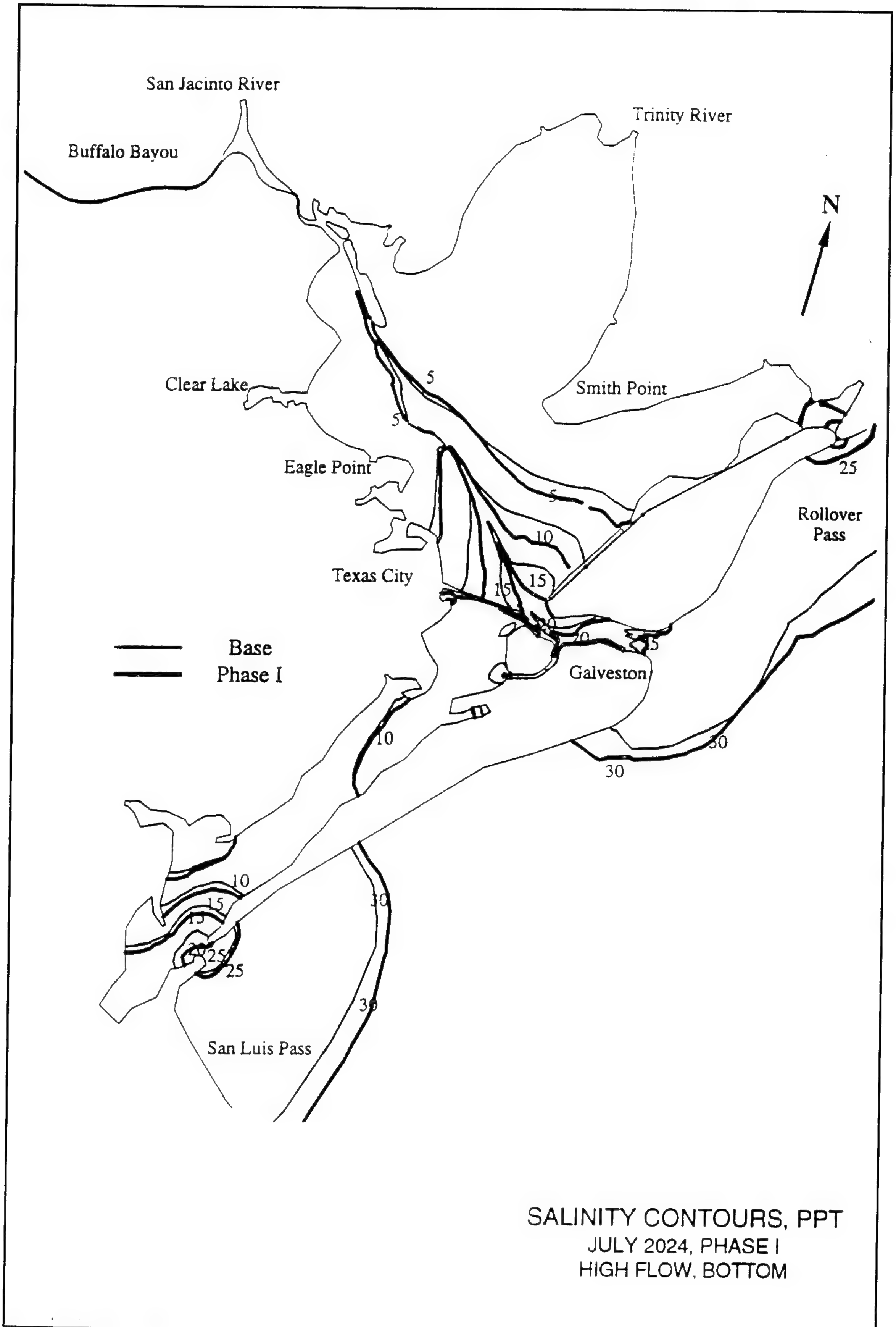
SALINITY CONTOURS, PPT
APRIL 2024, PHASE I
HIGH FLOW, BOTTOM



SALINITY CONTOURS, PPT
MAY 2024, PHASE I
HIGH FLOW, BOTTOM



SALINITY CONTOURS, PPT
JUNE 2024, PHASE I
HIGH FLOW, BOTTOM


San Jacinto River
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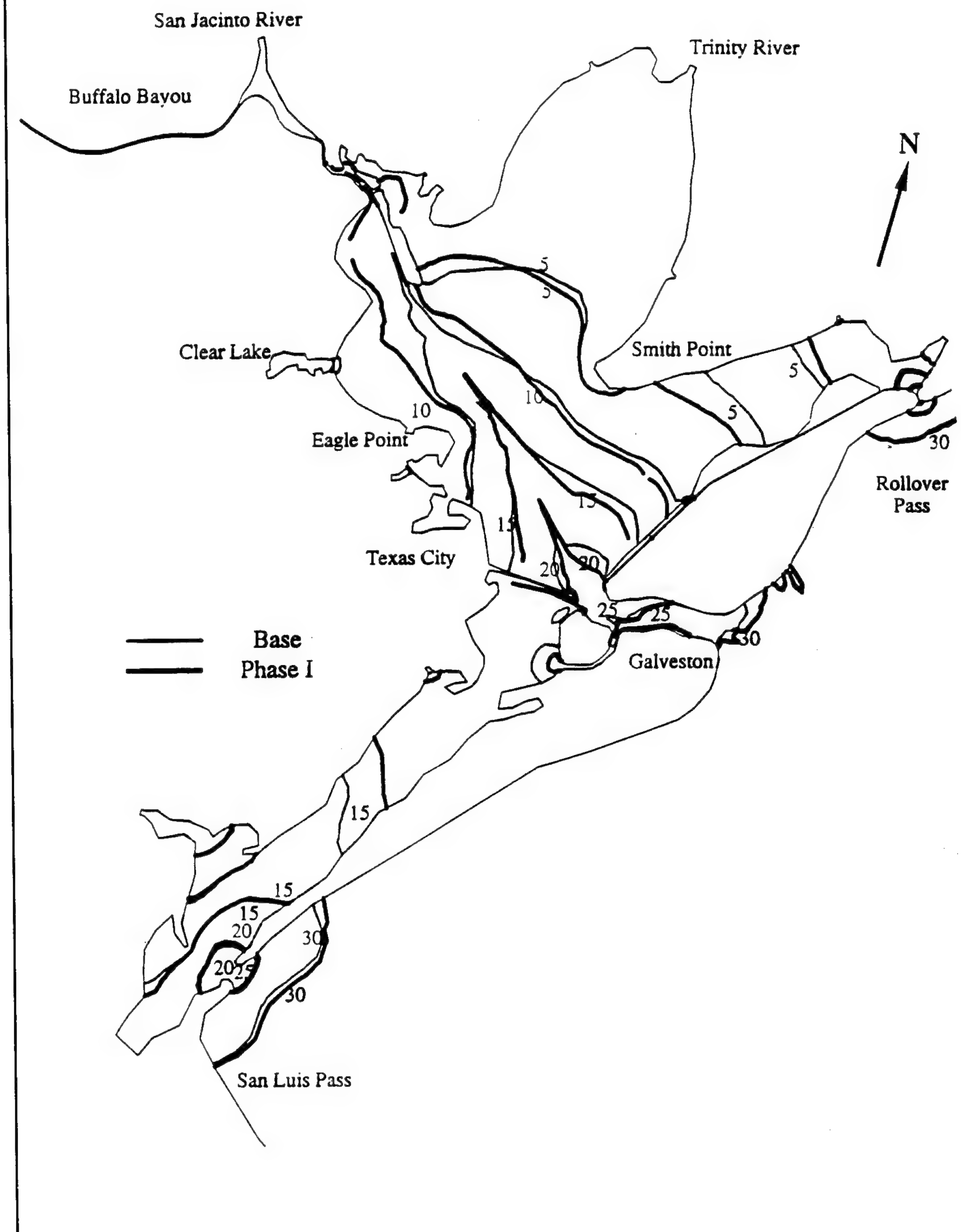
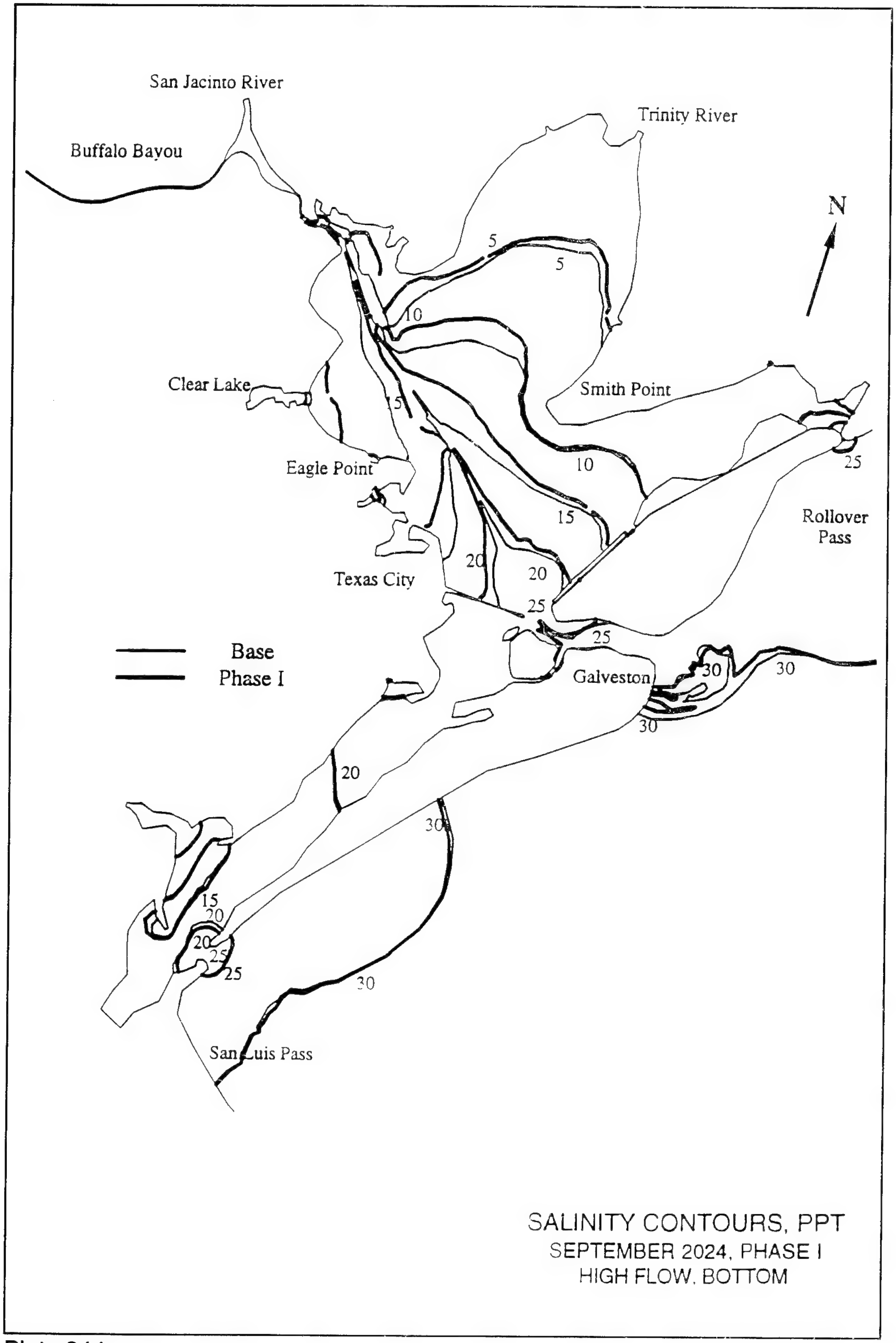
SALINITY CONTOURS, PPT
JULY 2024, PHASE I
HIGH FLOW, BOTTOM



SALINITY CONTOURS, PPT
AUGUST 2024, PHASE I
HIGH FLOW, BOTTOM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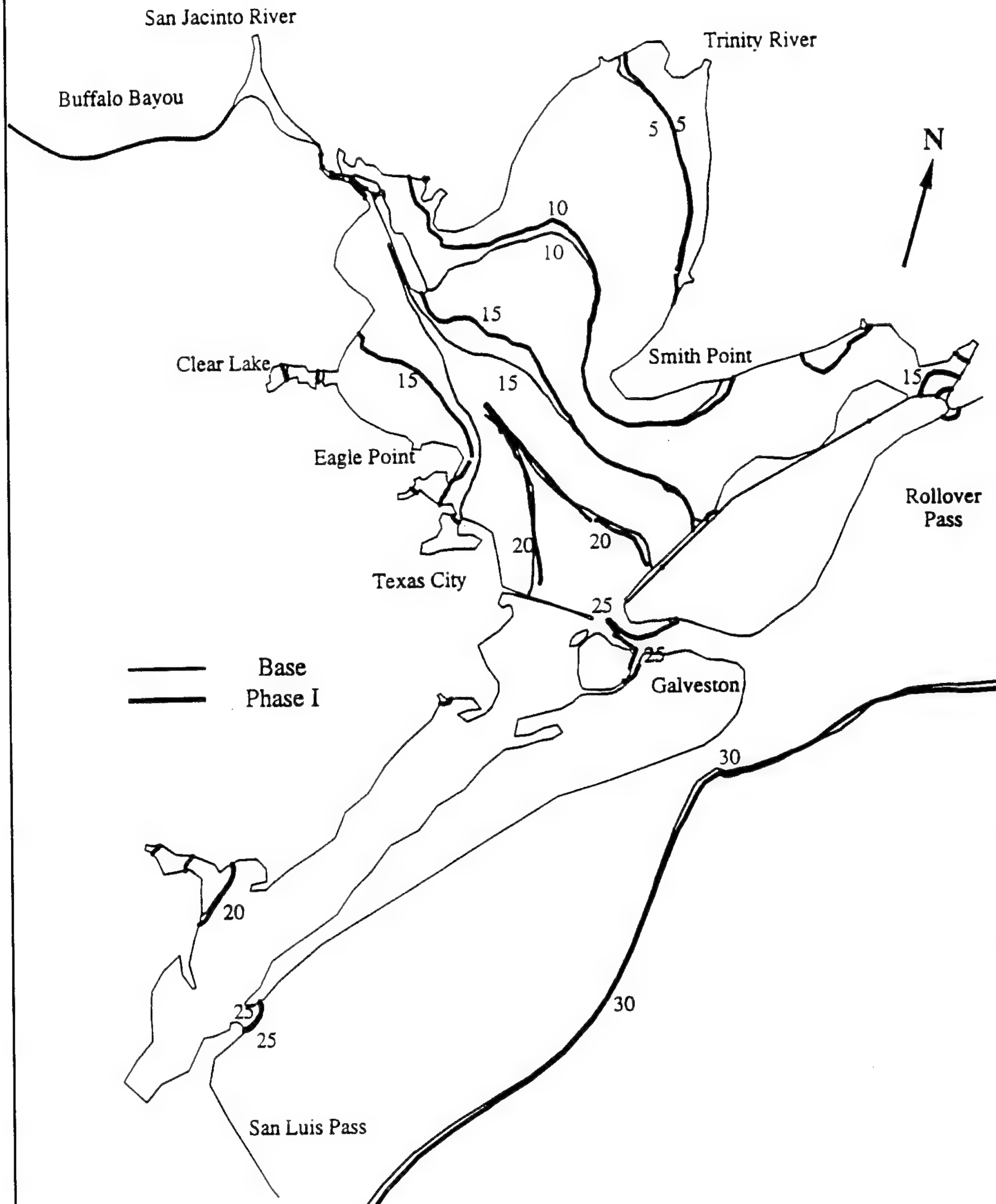
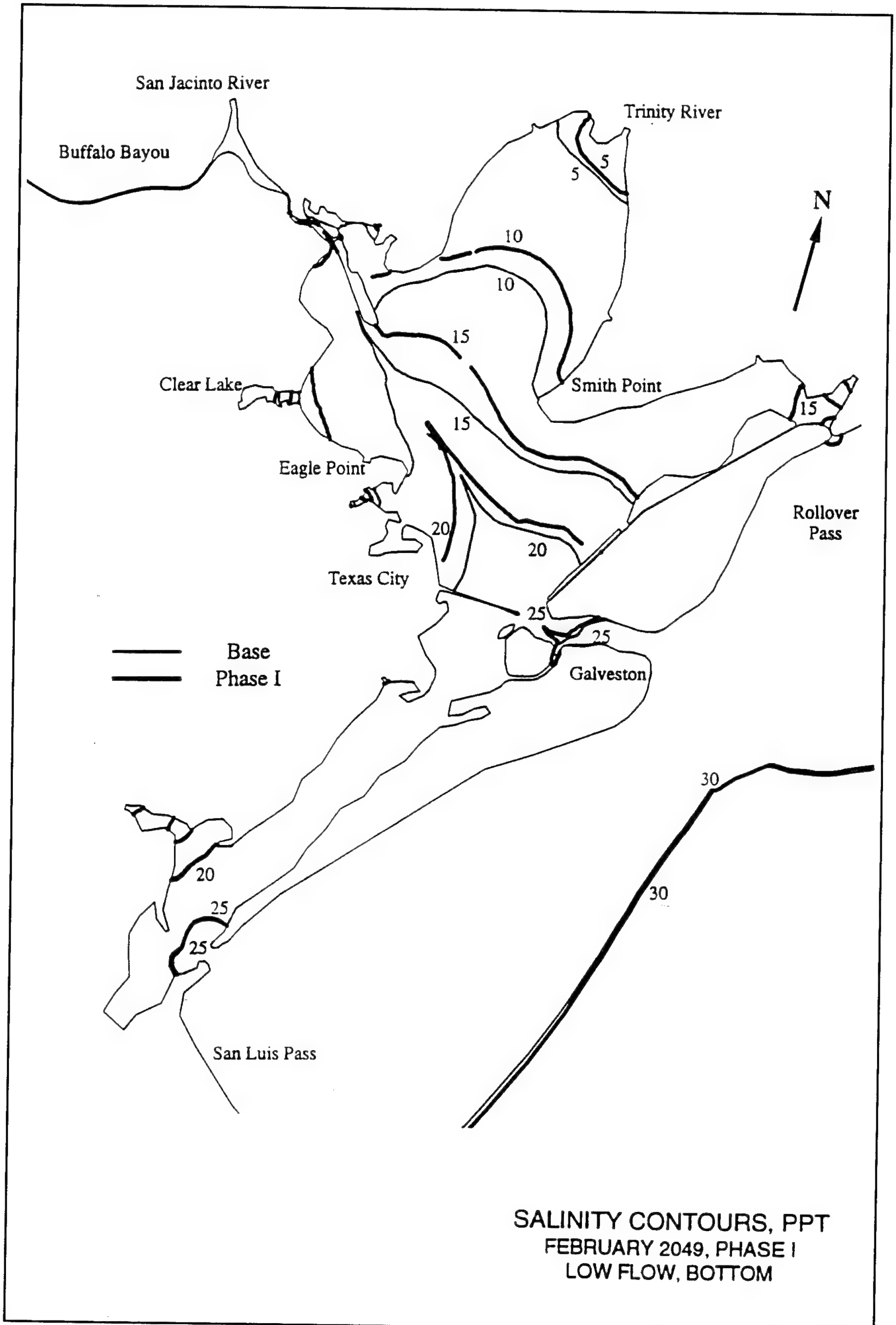
SALINITY CONTOURS, PPT
SEPTEMBER 2024, PHASE I
HIGH FLOW, BOTTOM

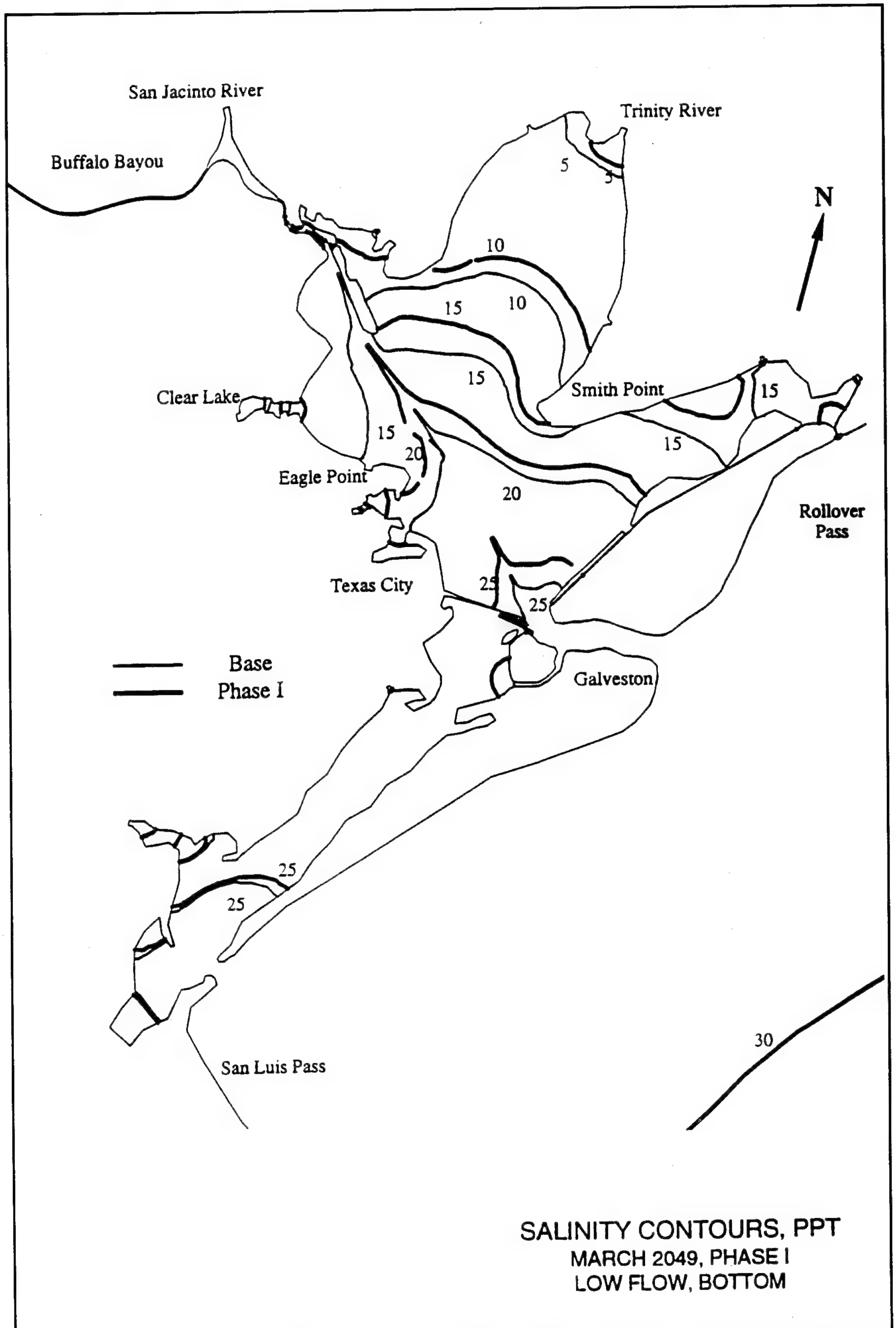
Plate 344



SALINITY CONTOURS, PPT
JANUARY 2049, PHASE I
LOW FLOW, BOTTOM



SALINITY CONTOURS, PPT
FEBRUARY 2049, PHASE I
LOW FLOW, BOTTOM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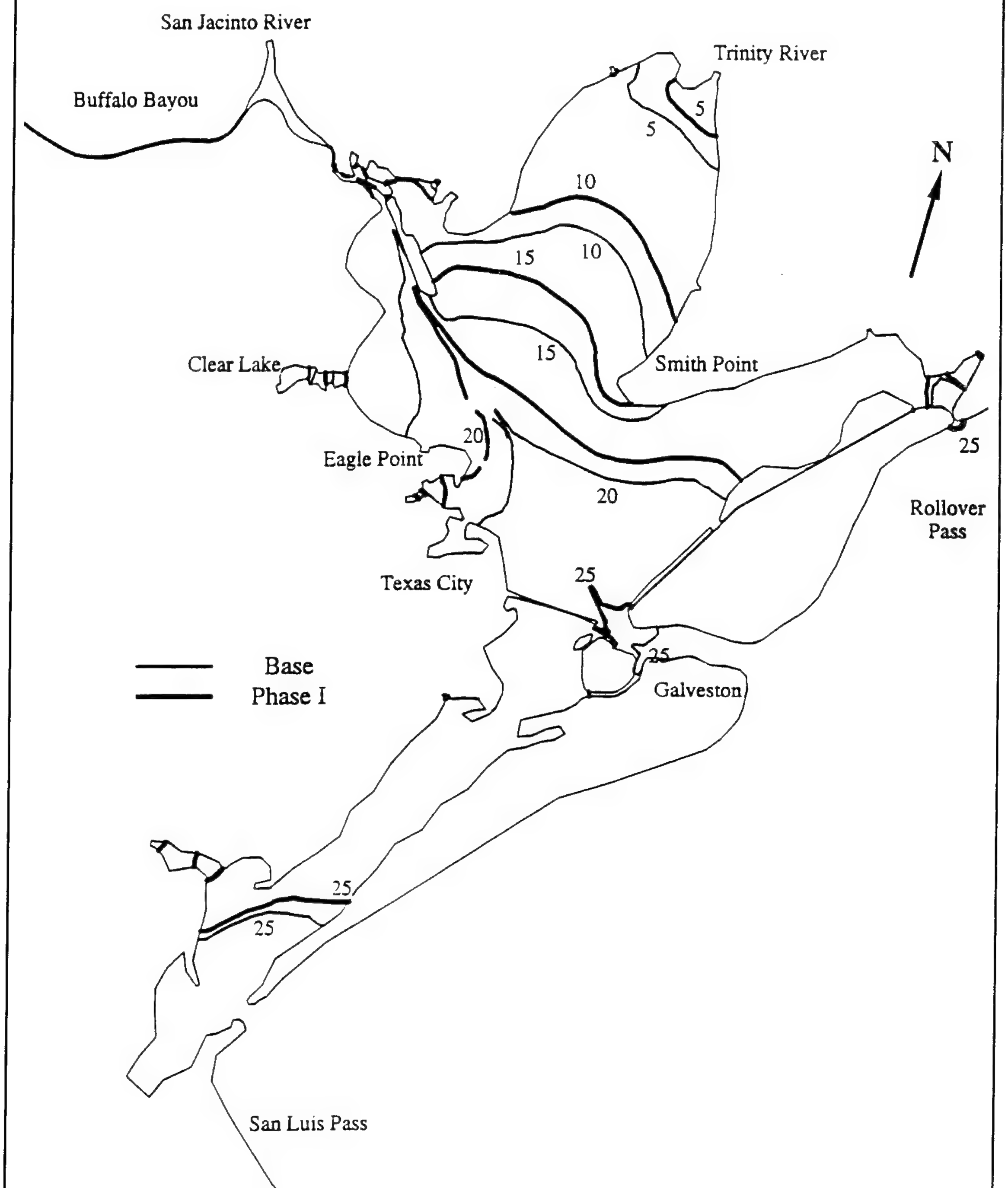
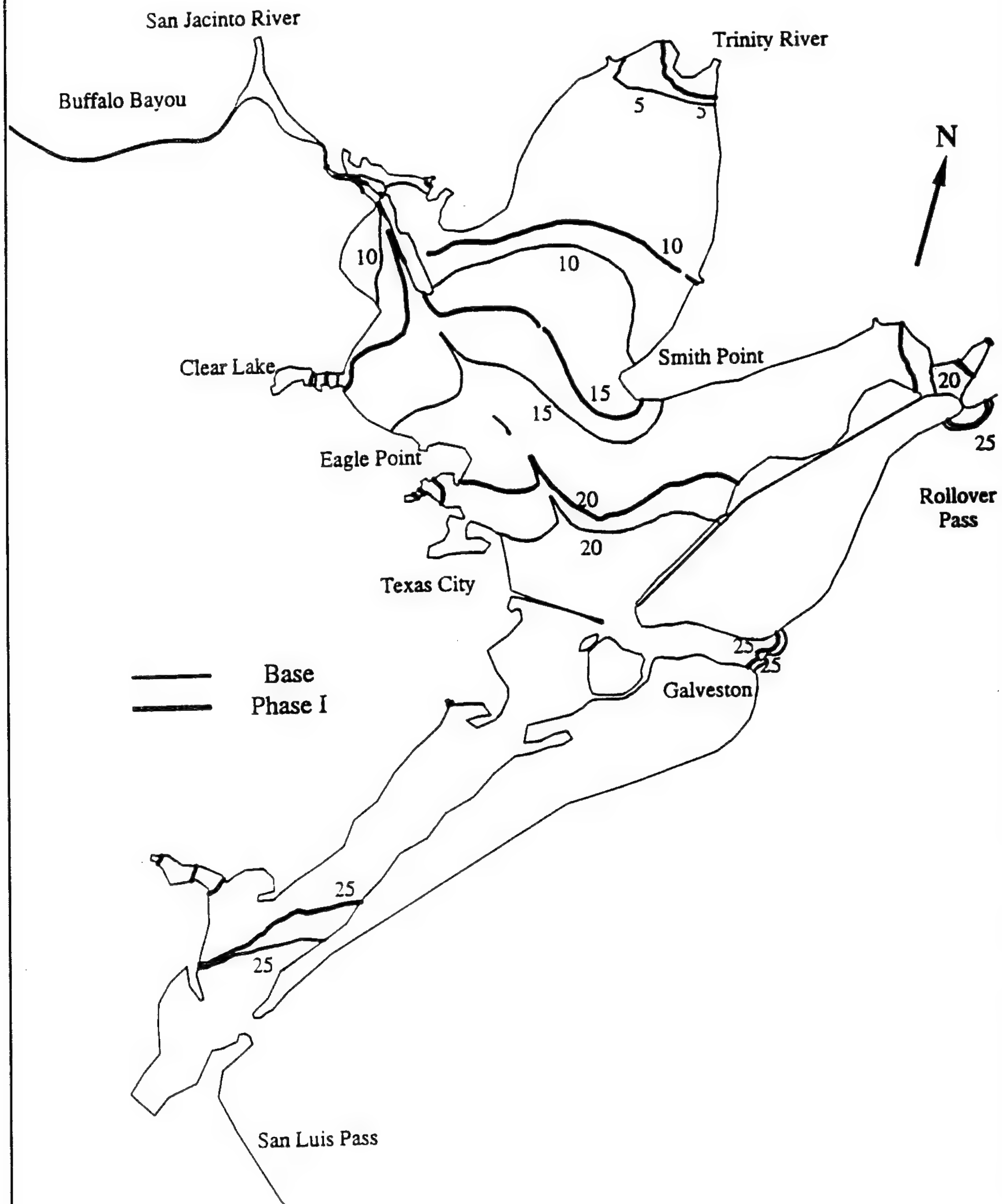
SALINITY CONTOURS, PPT
MARCH 2049, PHASE I
LOW FLOW, BOTTOM

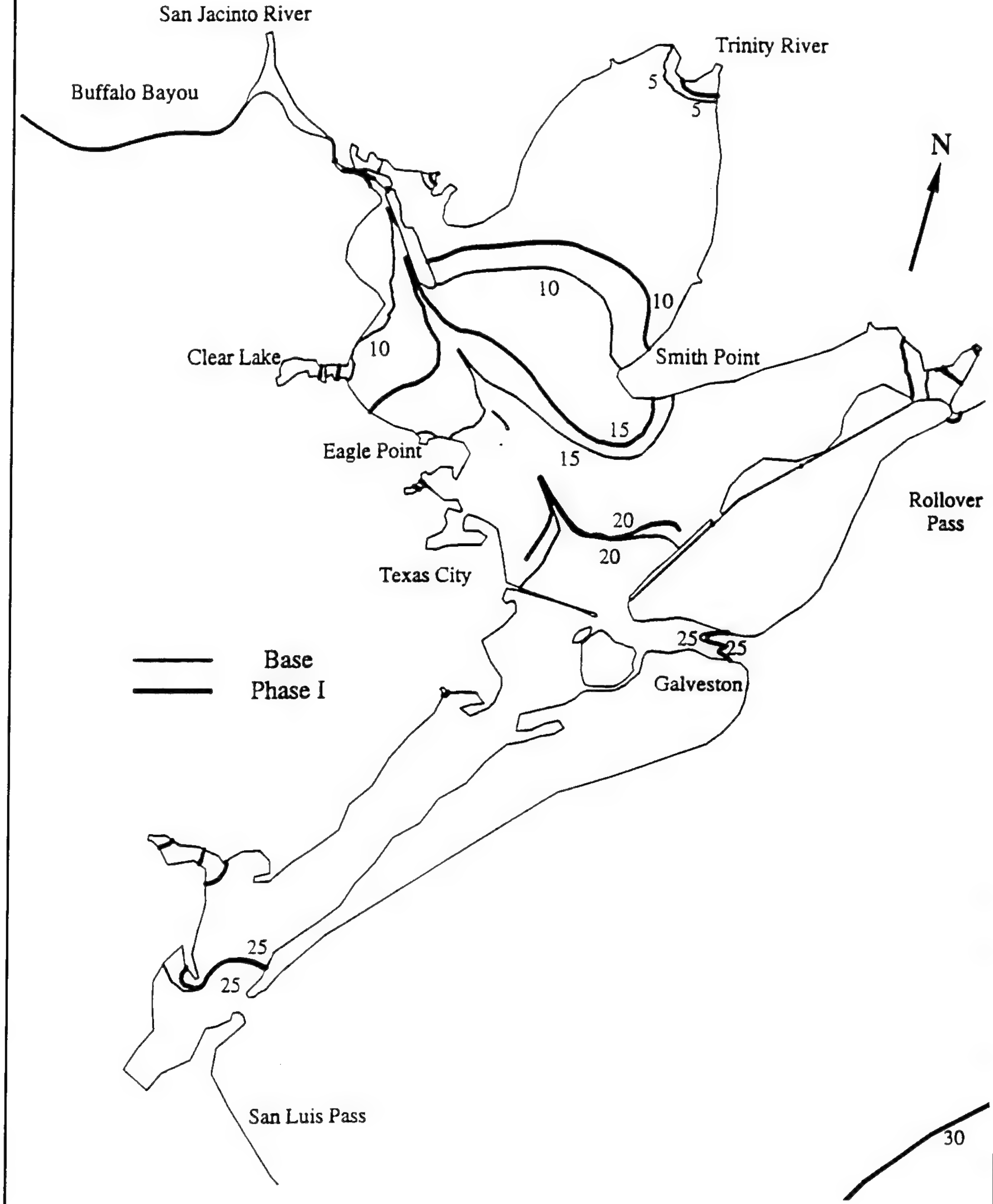


SALINITY CONTOURS, PPT
APRIL 2049, PHASE I
LOW FLOW, BOTTOM

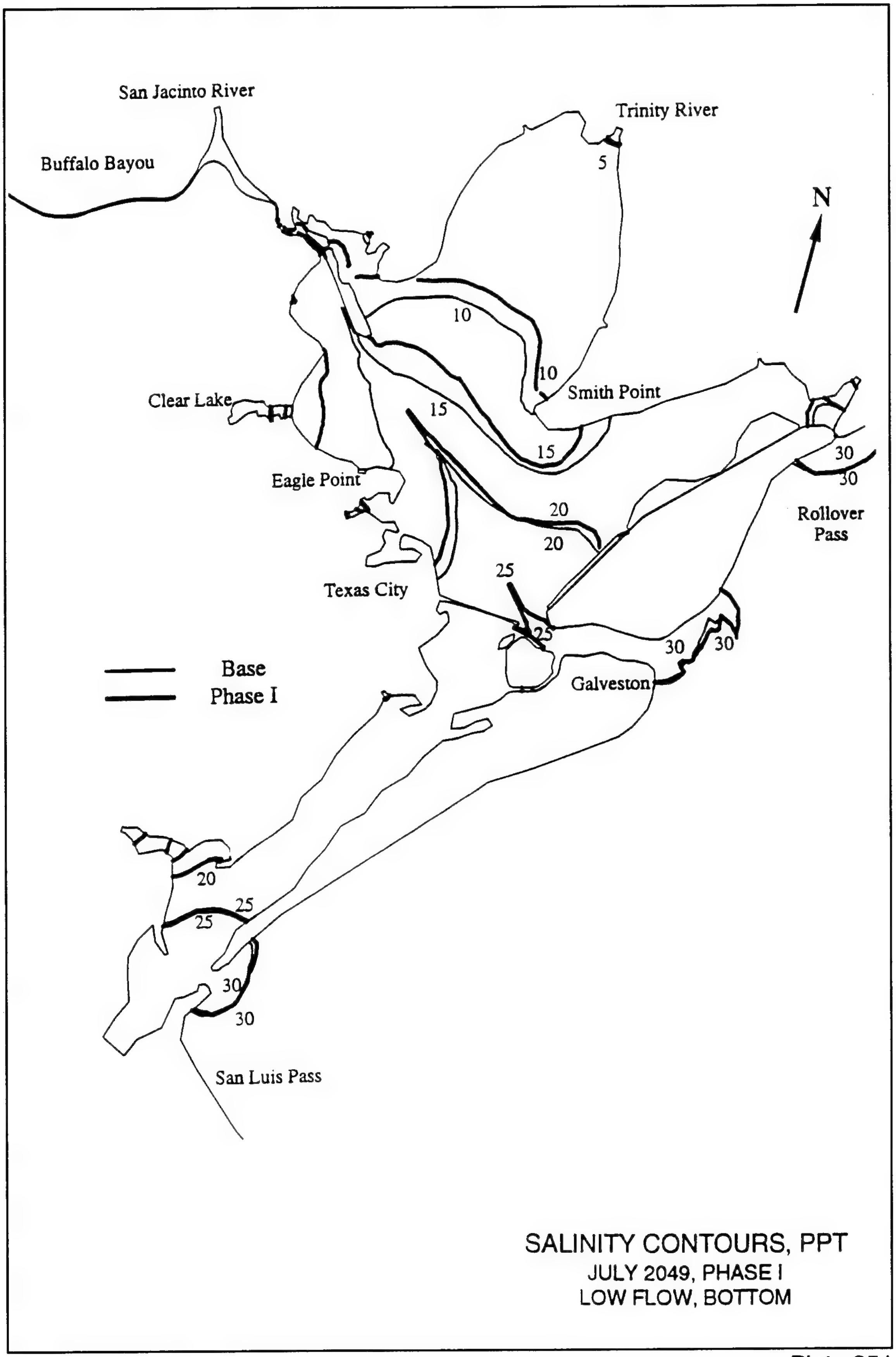
Plate 348



SALINITY CONTOURS, PPT
MAY 2049, PHASE I
LOW FLOW, BOTTOM



SALINITY CONTOURS, PPT
JUNE 2049, PHASE I
LOW FLOW, BOTTOM



San Jacinto River
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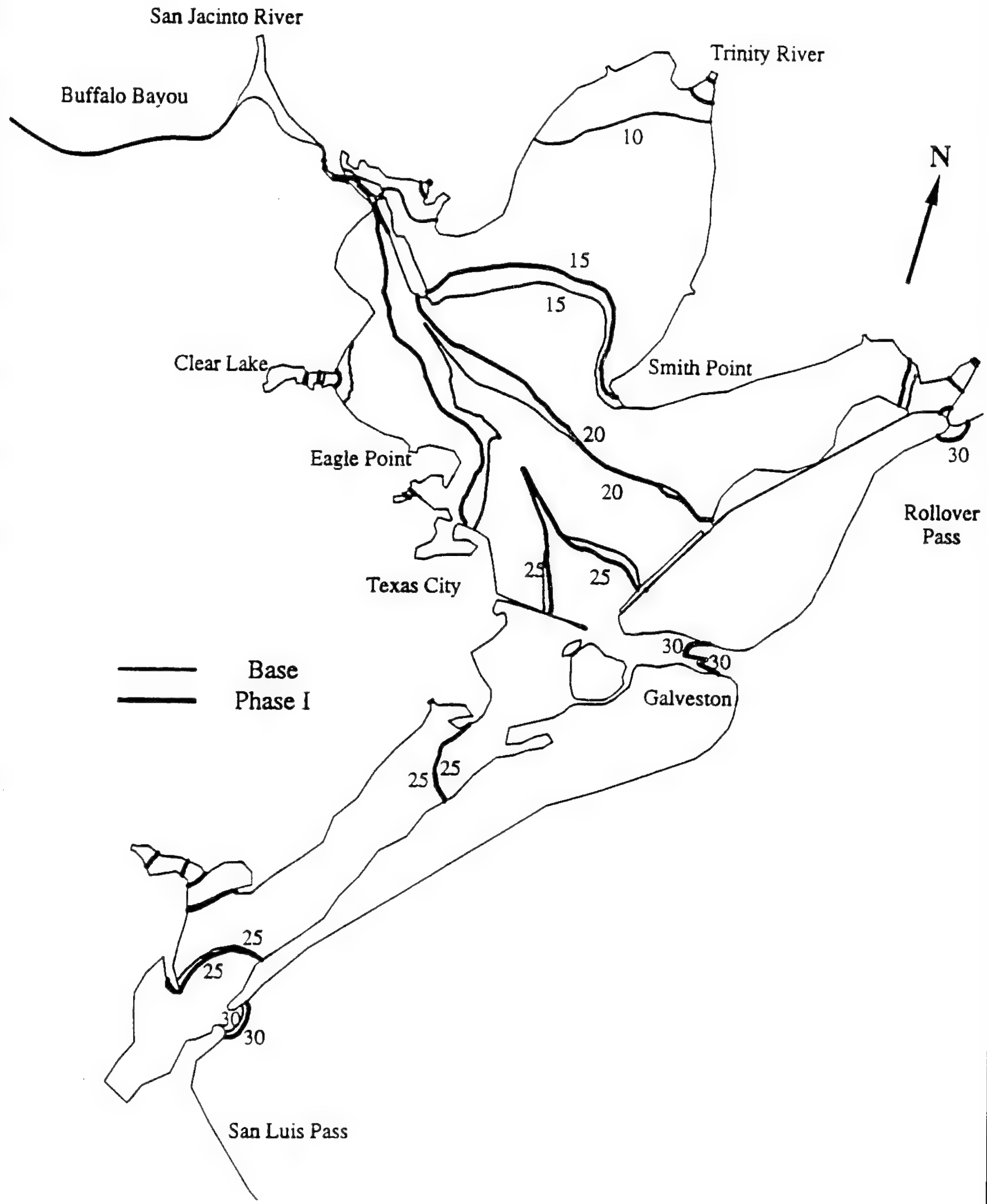
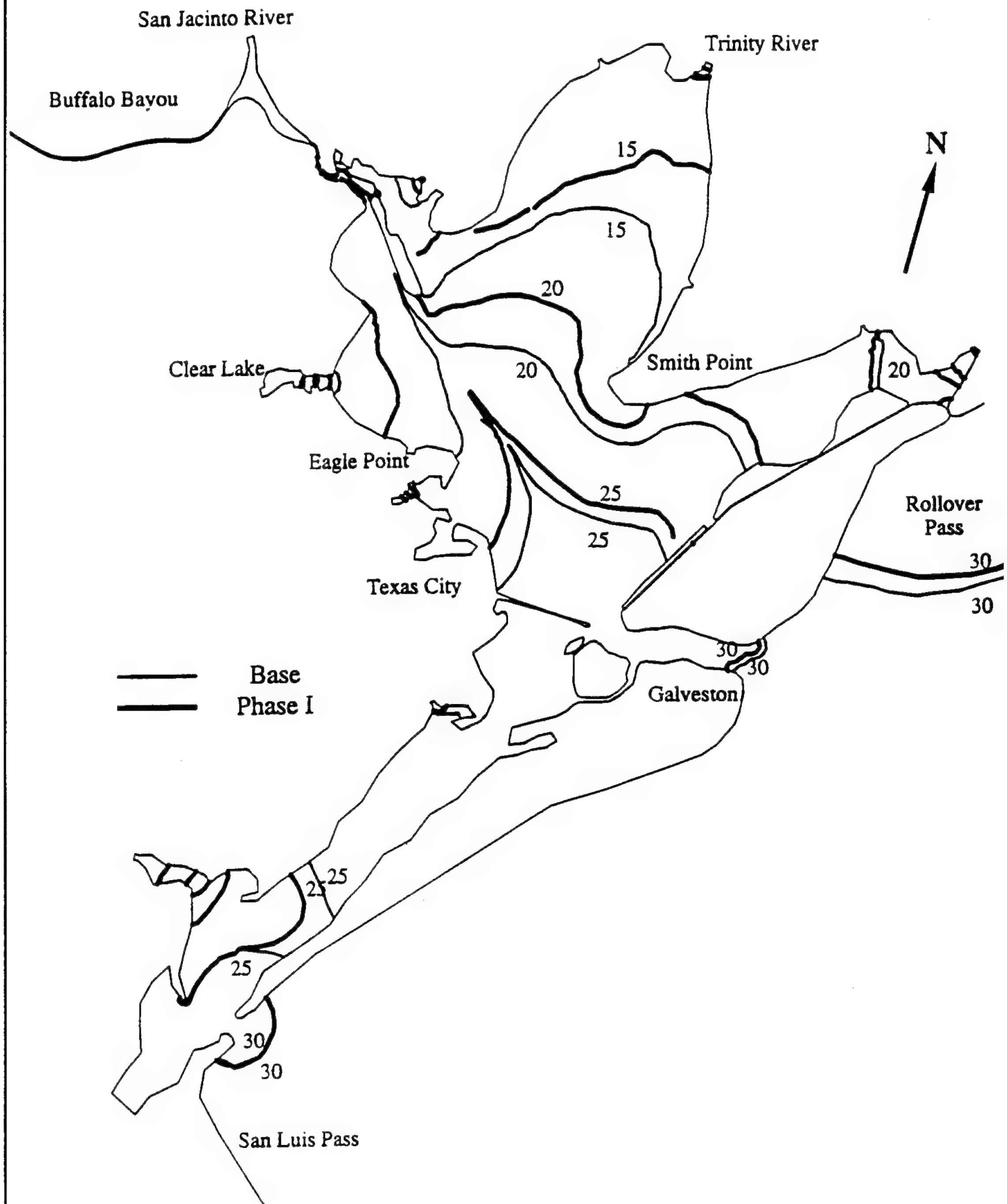
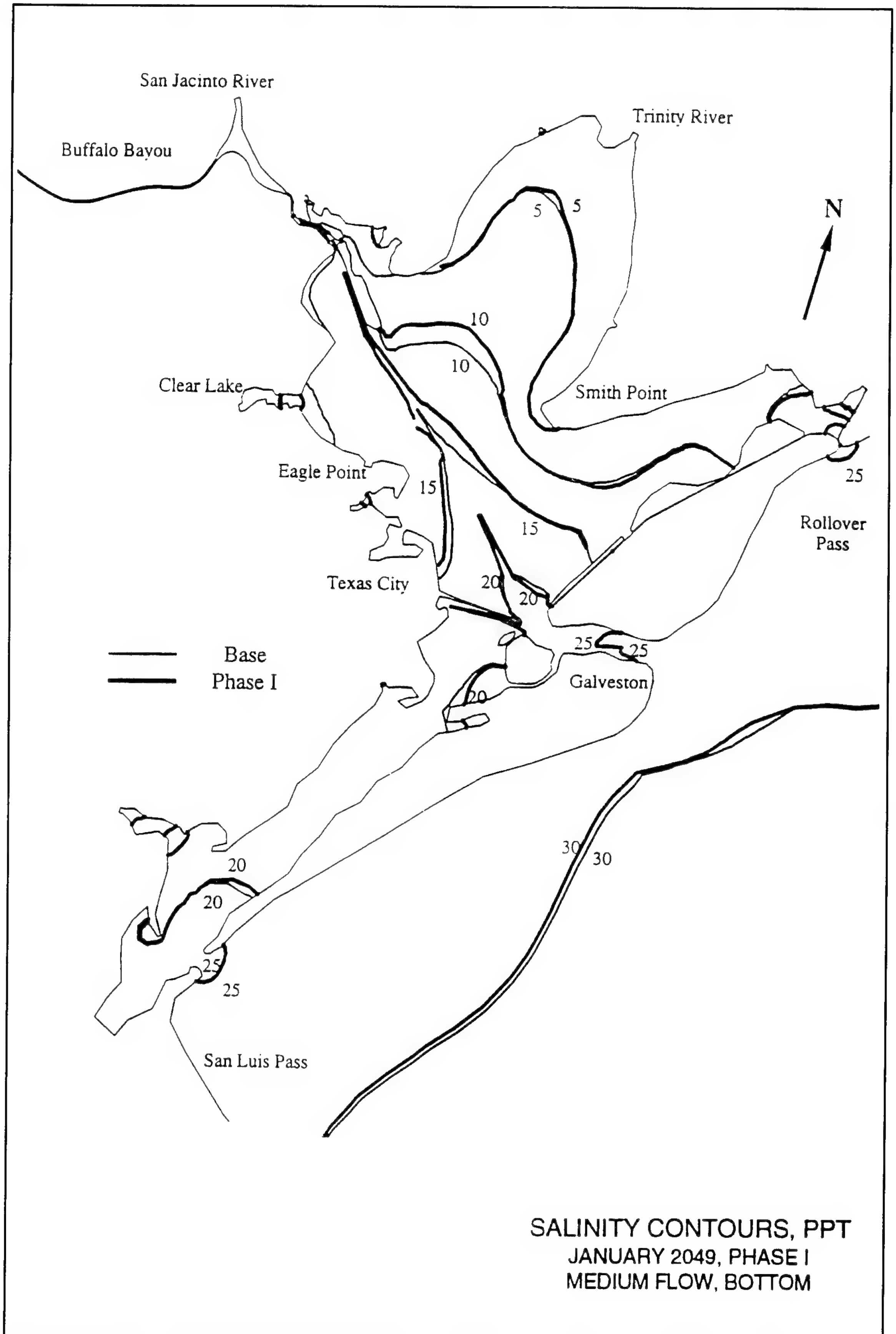
San Luis Pass
SALINITY CONTOURS, PPT
JULY 2049, PHASE I
LOW FLOW, BOTTOM



SALINITY CONTOURS, PPT
AUGUST 2049, PHASE I
LOW FLOW, BOTTOM



SALINITY CONTOURS, PPT
SEPTEMBER 2049, PHASE I
LOW FLOW, BOTTOM


San Jacinto River
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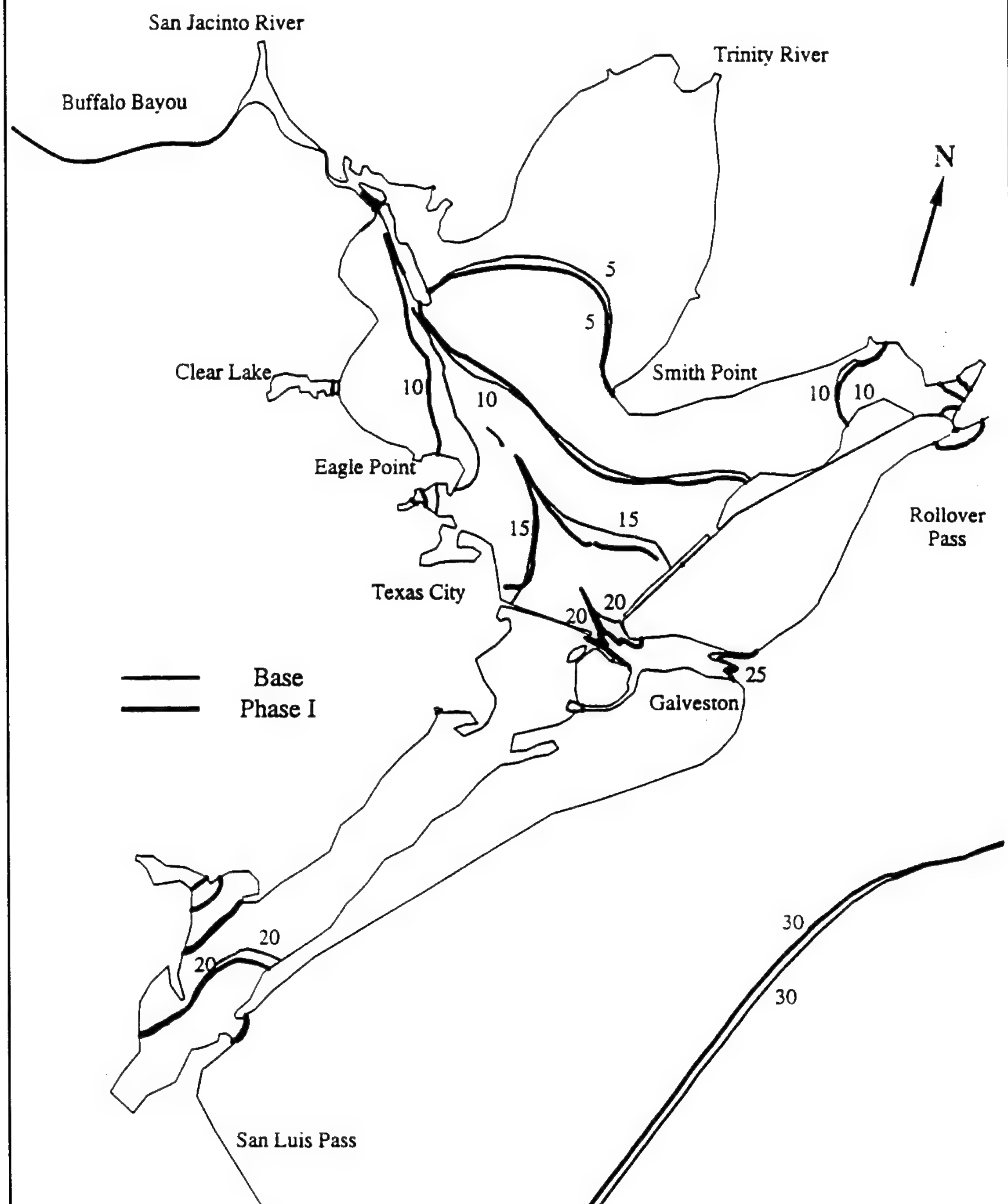
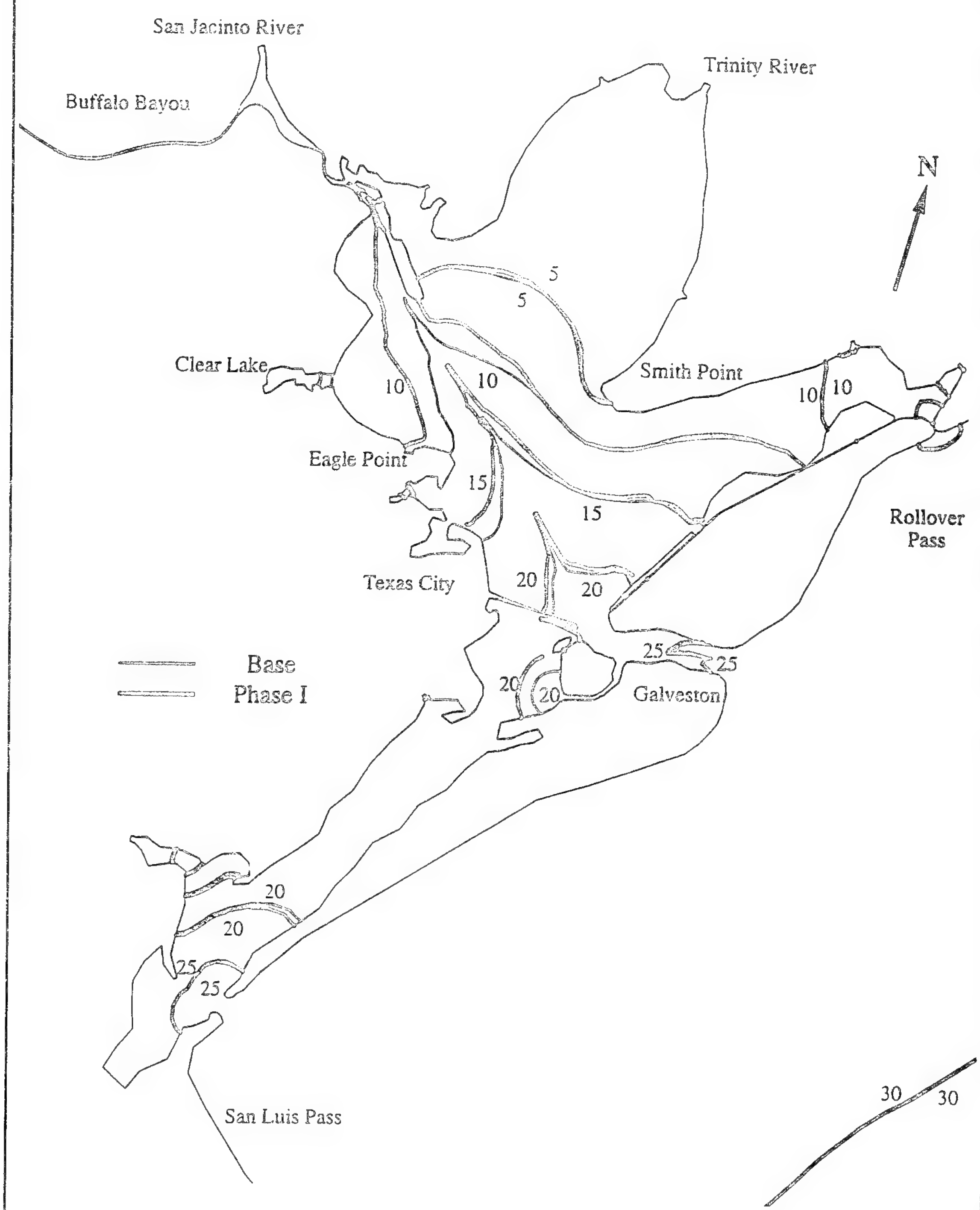
San Luis Pass
SALINITY CONTOURS, PPT
JANUARY 2049, PHASE I
MEDIUM FLOW, BOTTOM

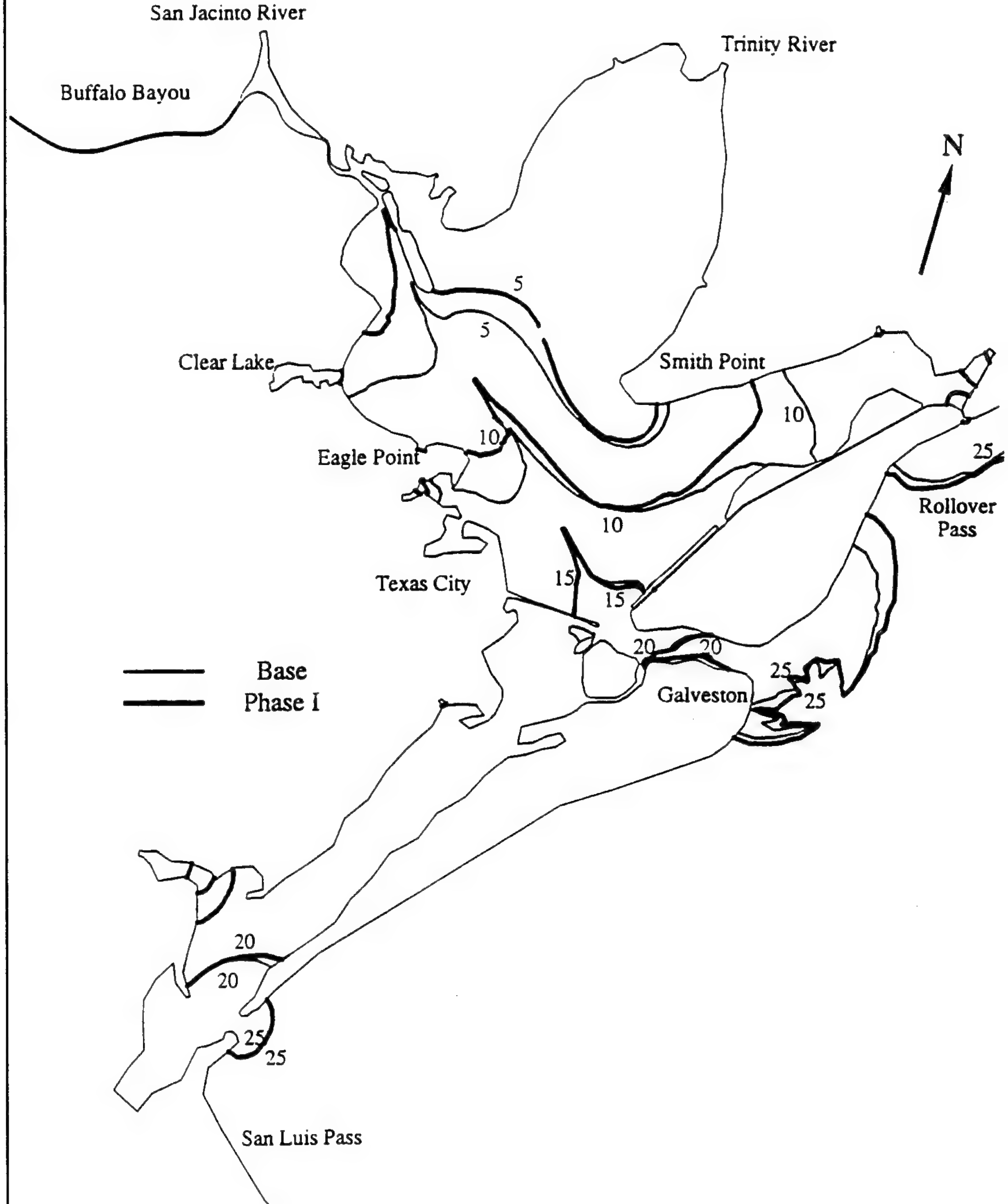
Plate 354



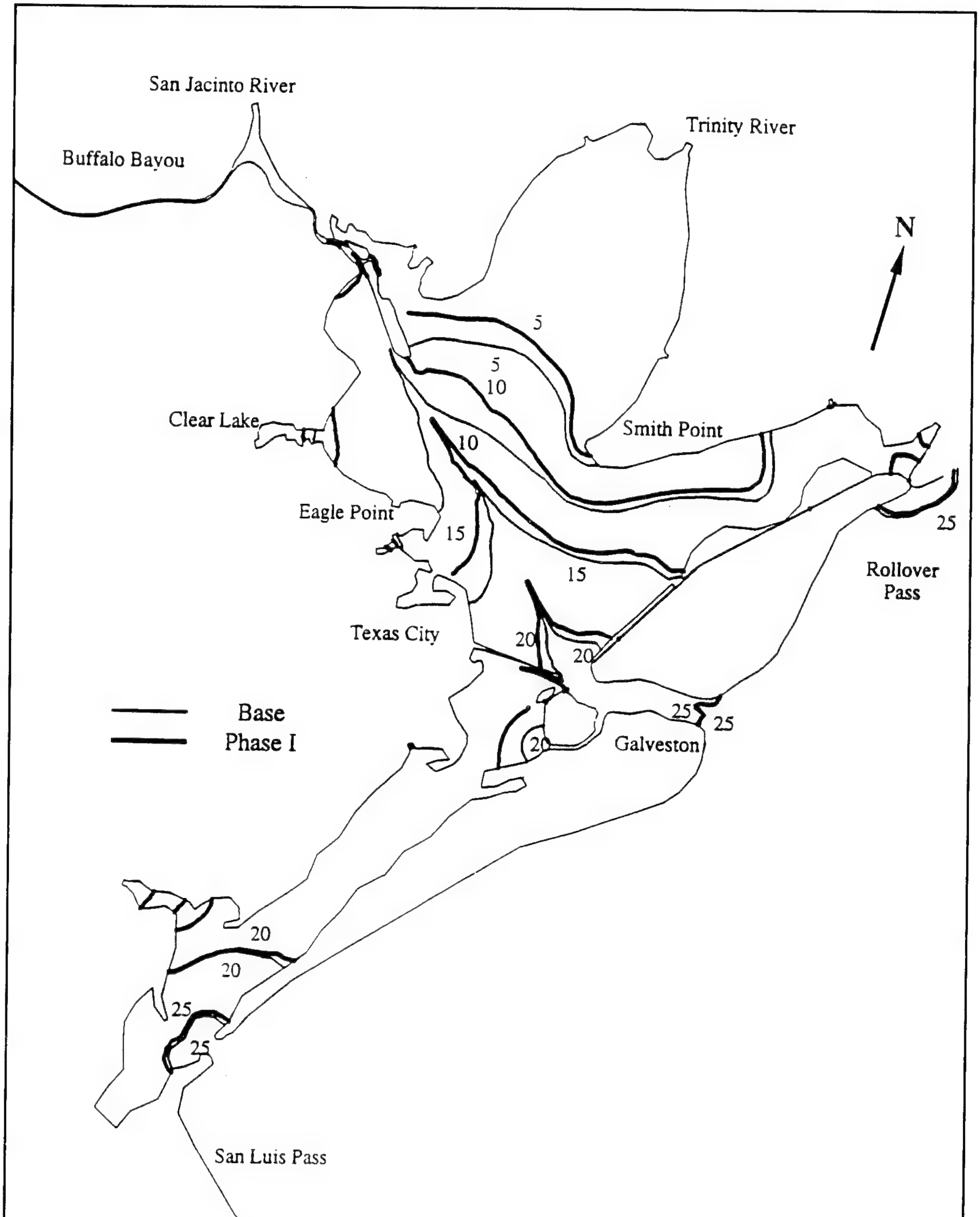
SALINITY CONTOURS, PPT
FEBRUARY 2049, PHASE I
MEDIUM FLOW, BOTTOM



SALINITY CONTOURS, PPT
MARCH 2049, PHASE I
MEDIUM FLOW, BOTTOM

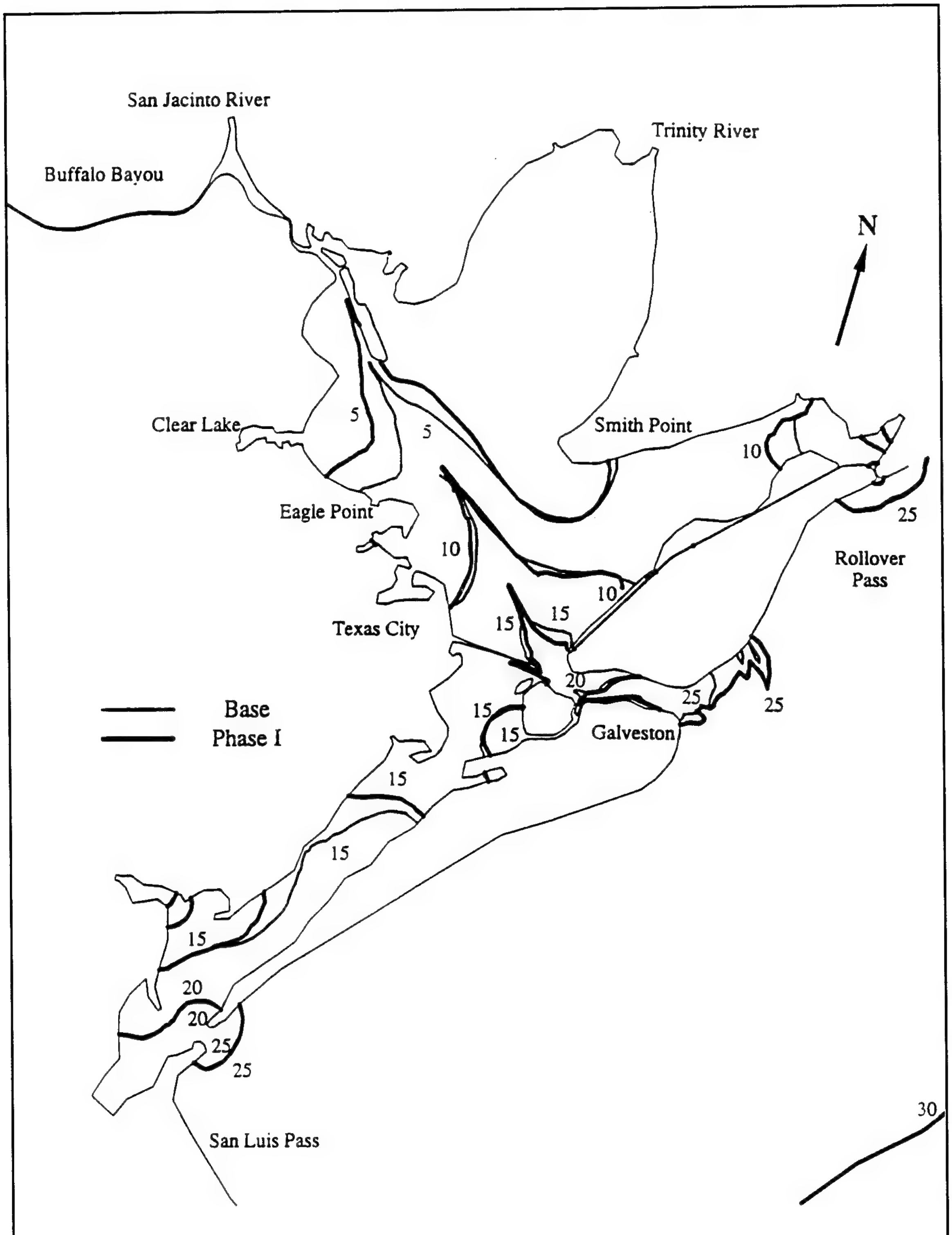


SALINITY CONTOURS, PPT
APRIL 2049 PHASE I
MEDIUM FLOW, BOTTOM



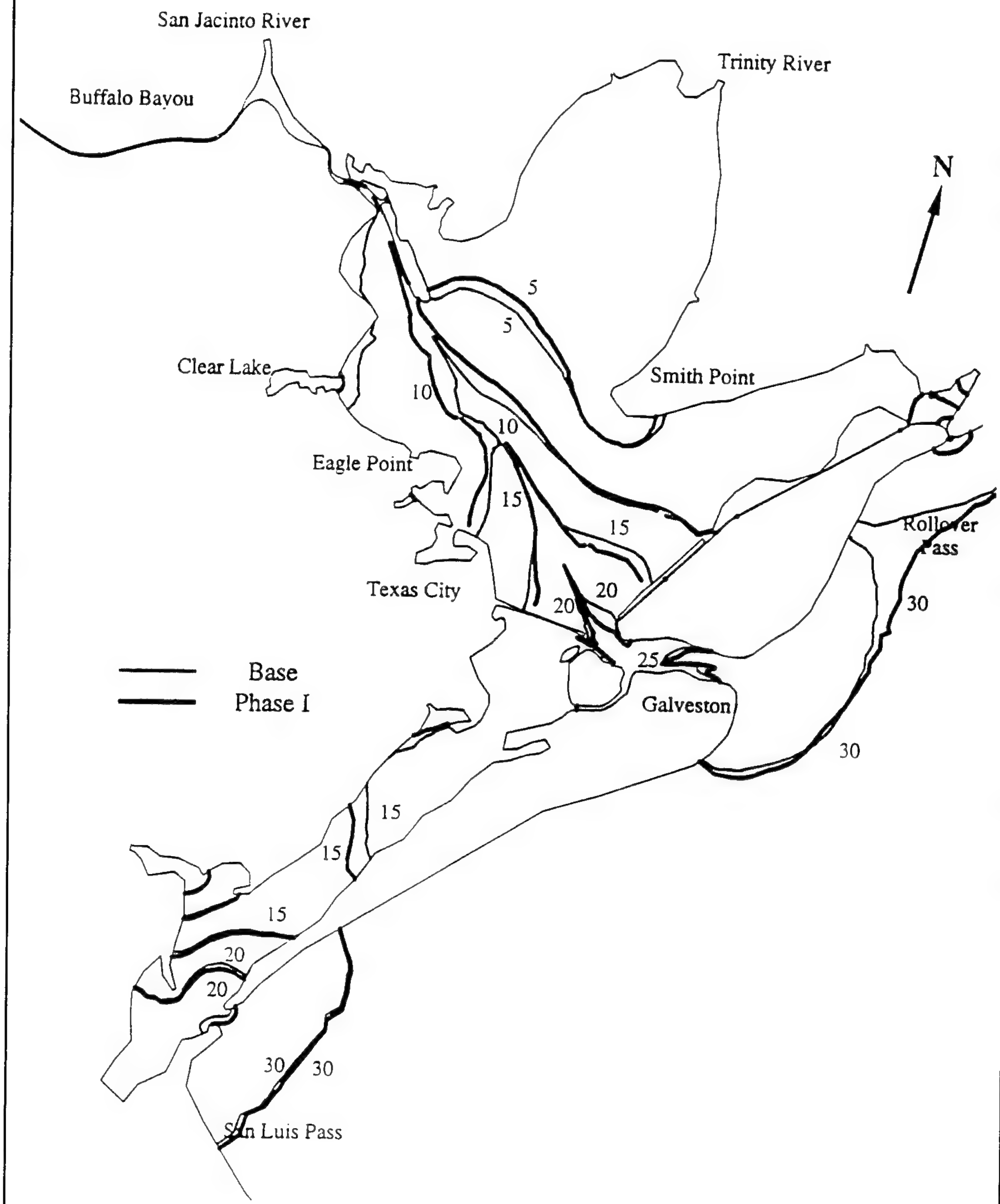
SALINITY CONTOURS, PPT
MAY 2049, PHASE I
MEDIUM FLOW, BOTTOM

Plate 358

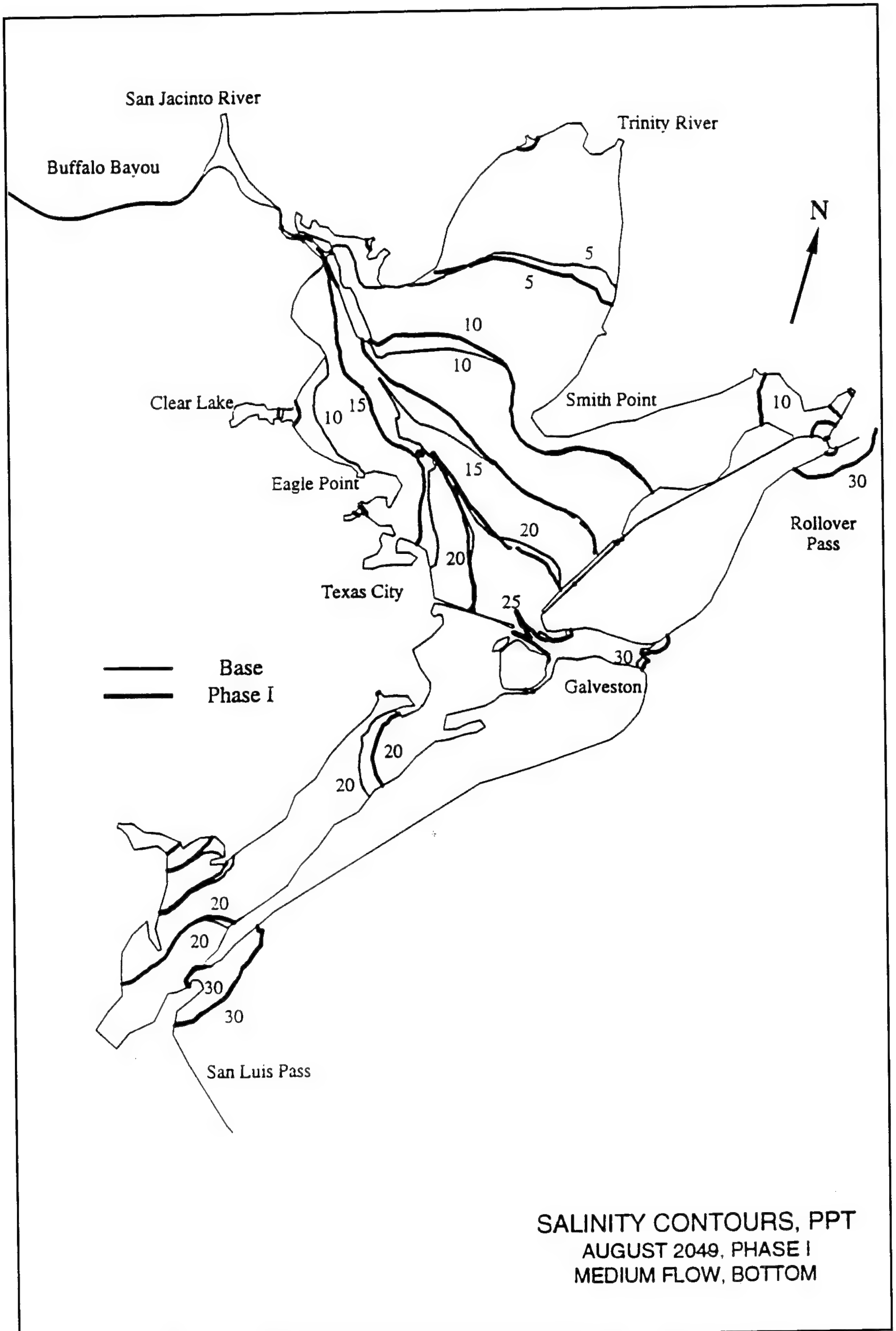


SALINITY CONTOURS, PPT
JUNE 2049, PHASE I
MEDIUM FLOW, BOTTOM

Plate 359



SALINITY CONTOURS, PPT
JULY 2049, PHASE I
MEDIUM FLOW, BOTTOM



San Jacinto River
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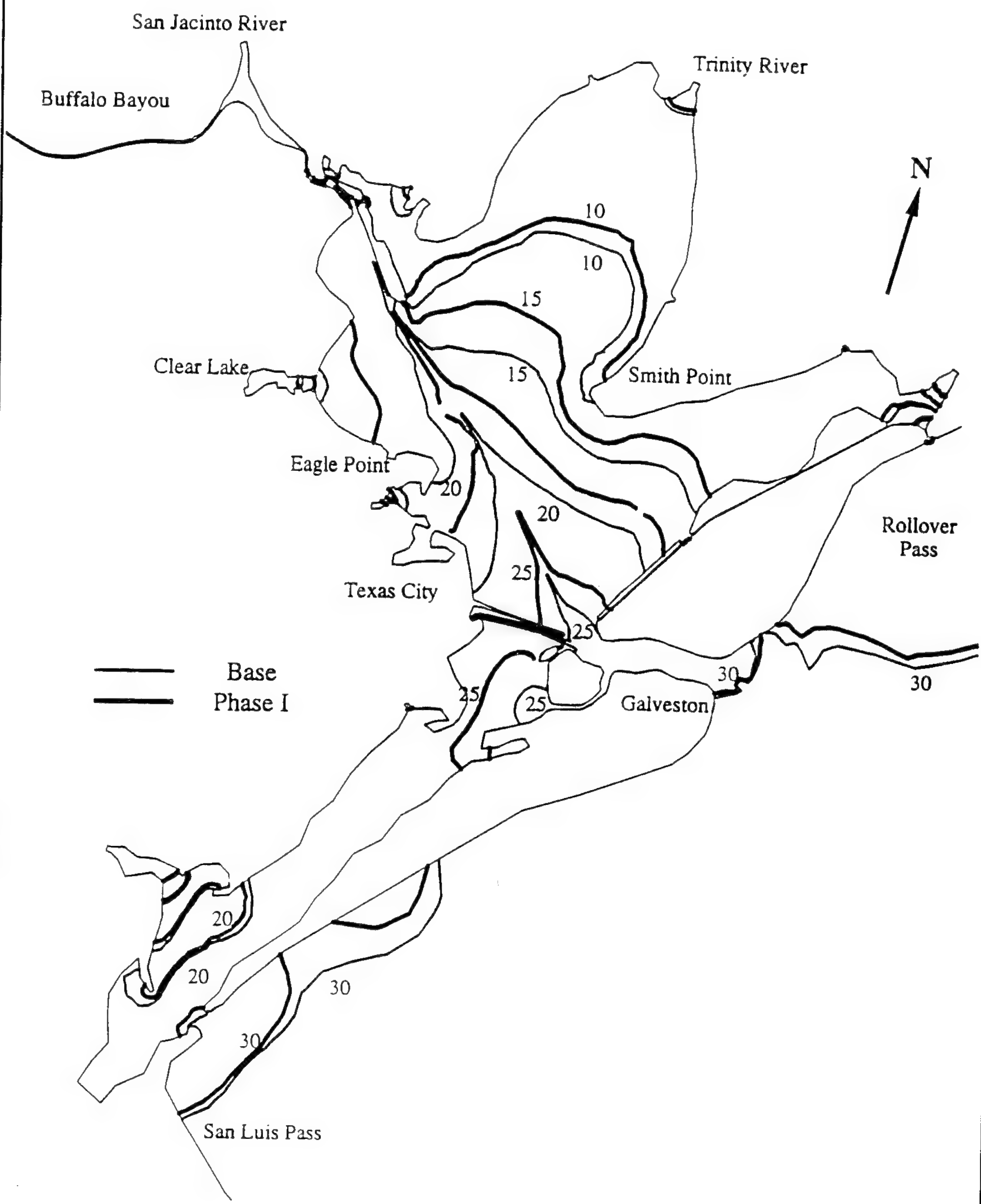
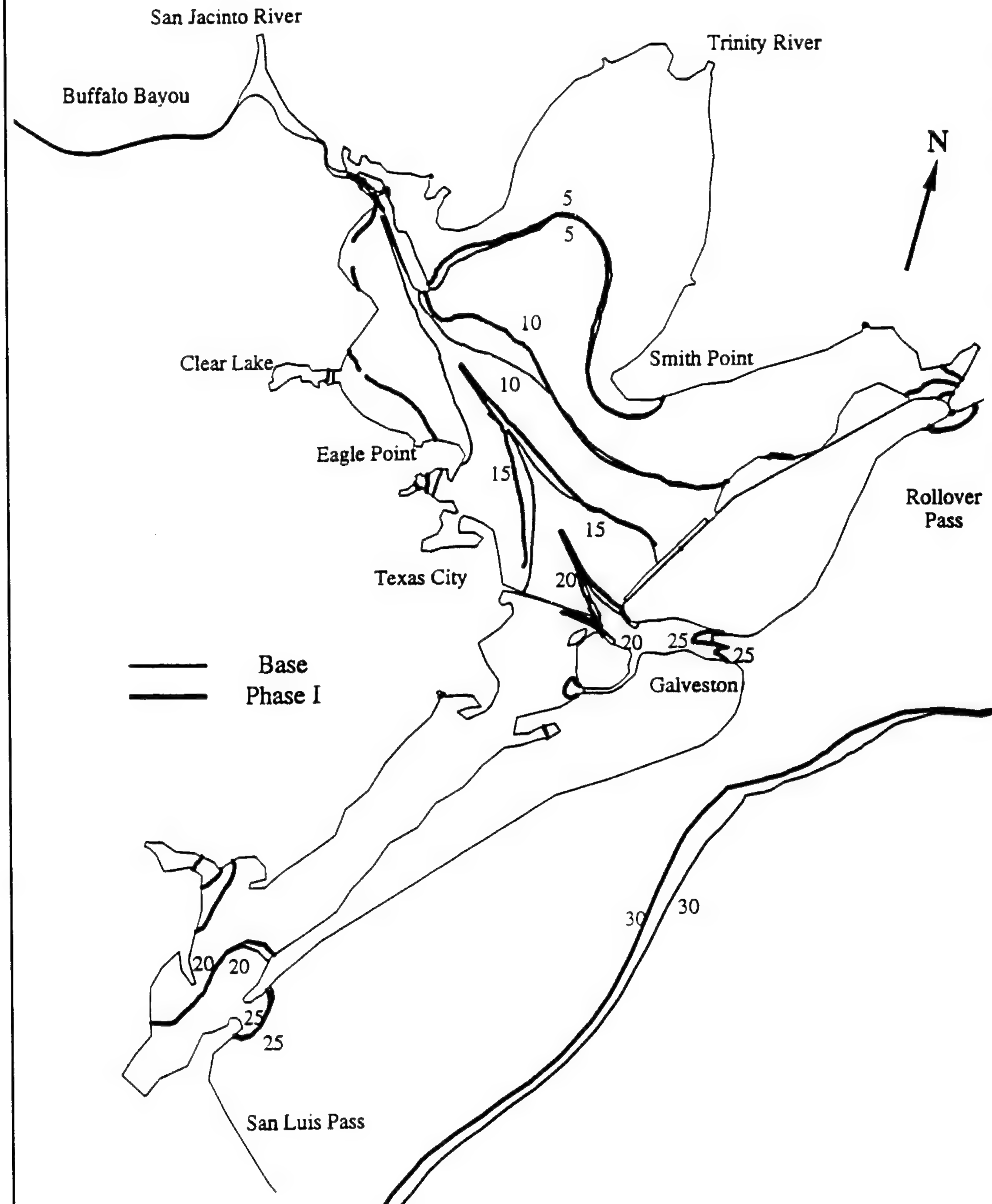
SALINITY CONTOURS, PPT
AUGUST 2049, PHASE I
MEDIUM FLOW, BOTTOM

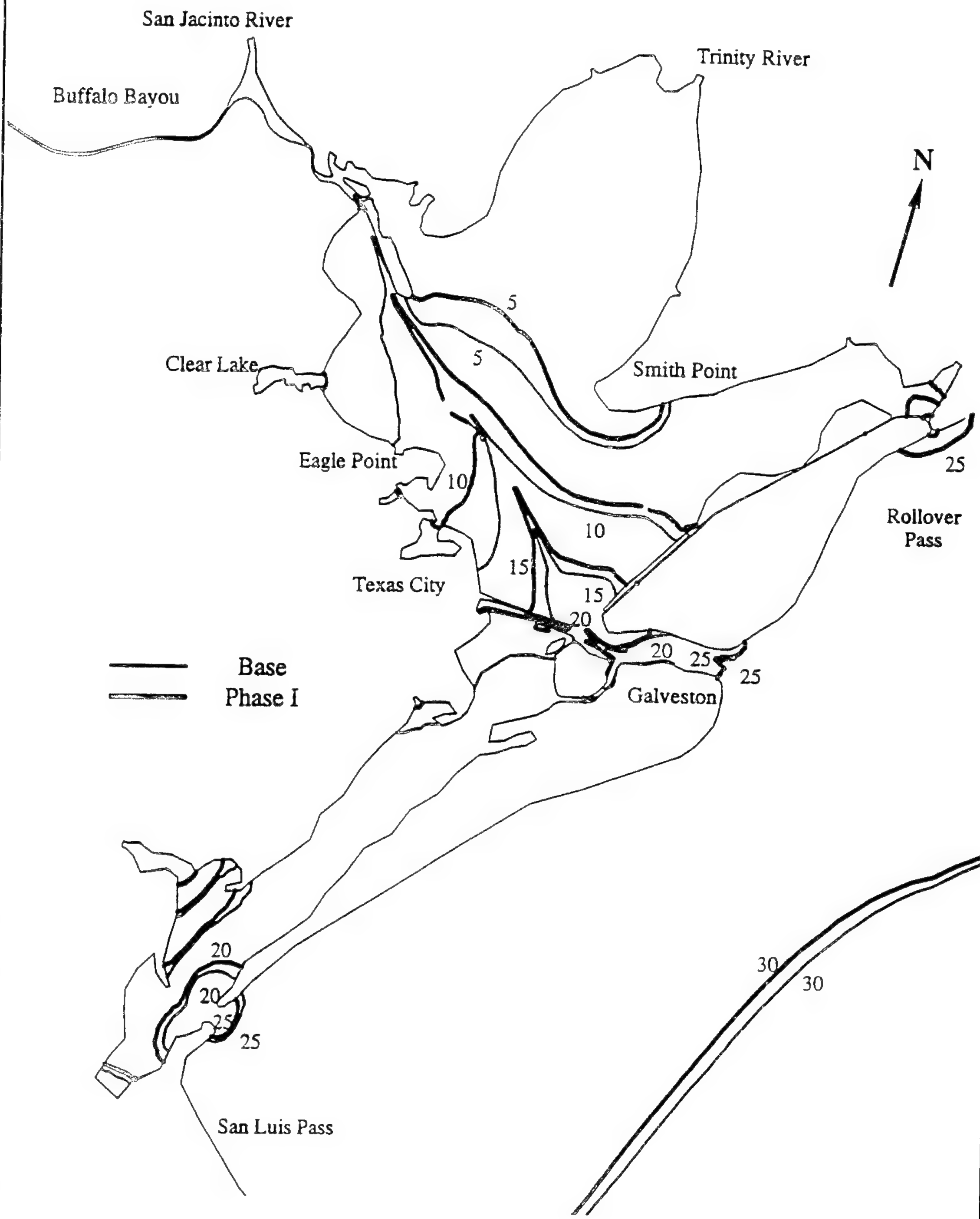


SALINITY CONTOURS, PPT
SEPTEMBER 2049, PHASE I
MEDIUM FLOW, BOTTOM

Plate 362

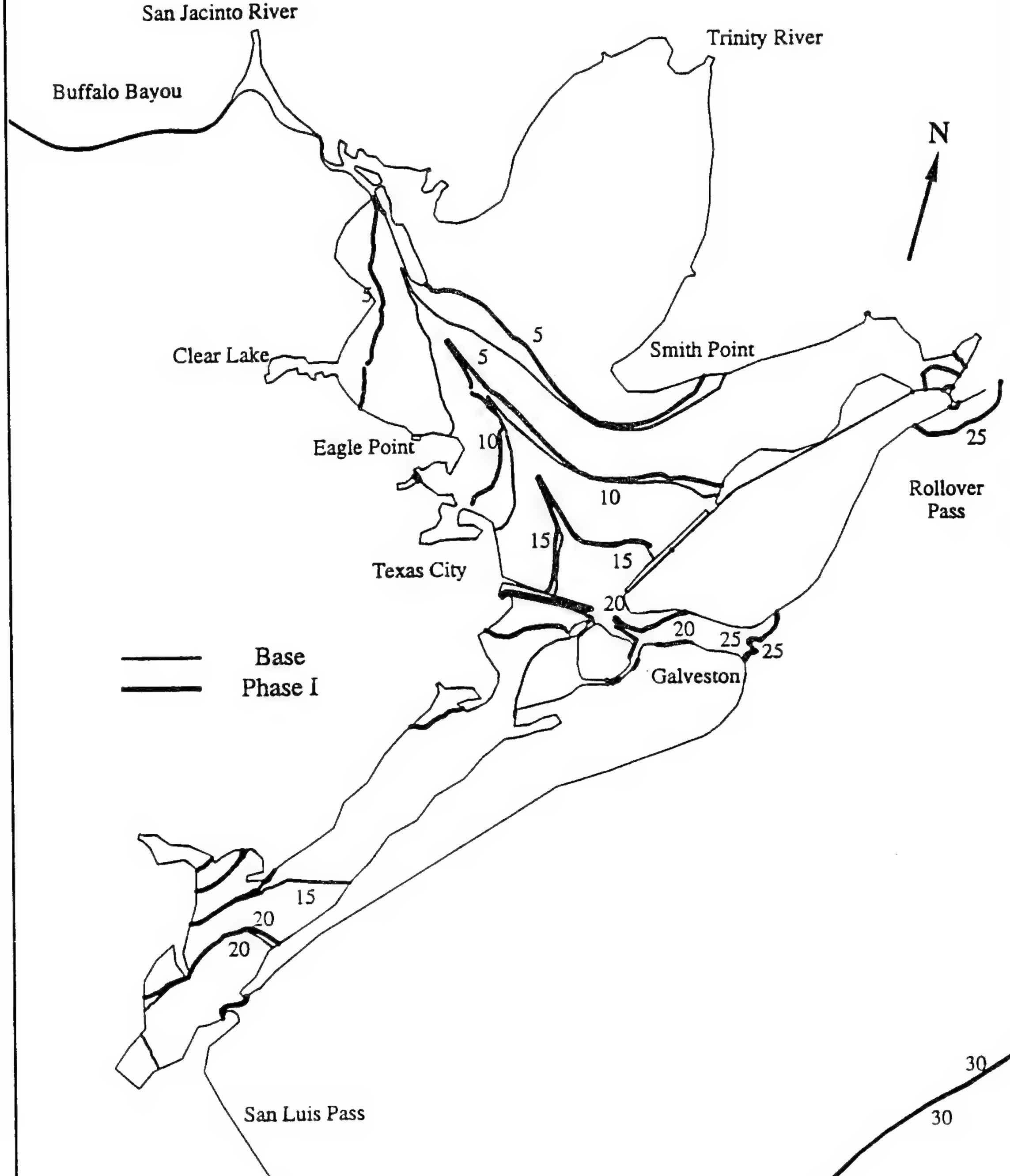


SALINITY CONTOURS, PPT
JANUARY 2049, PHASE I
HIGH FLOW, BOTTOM

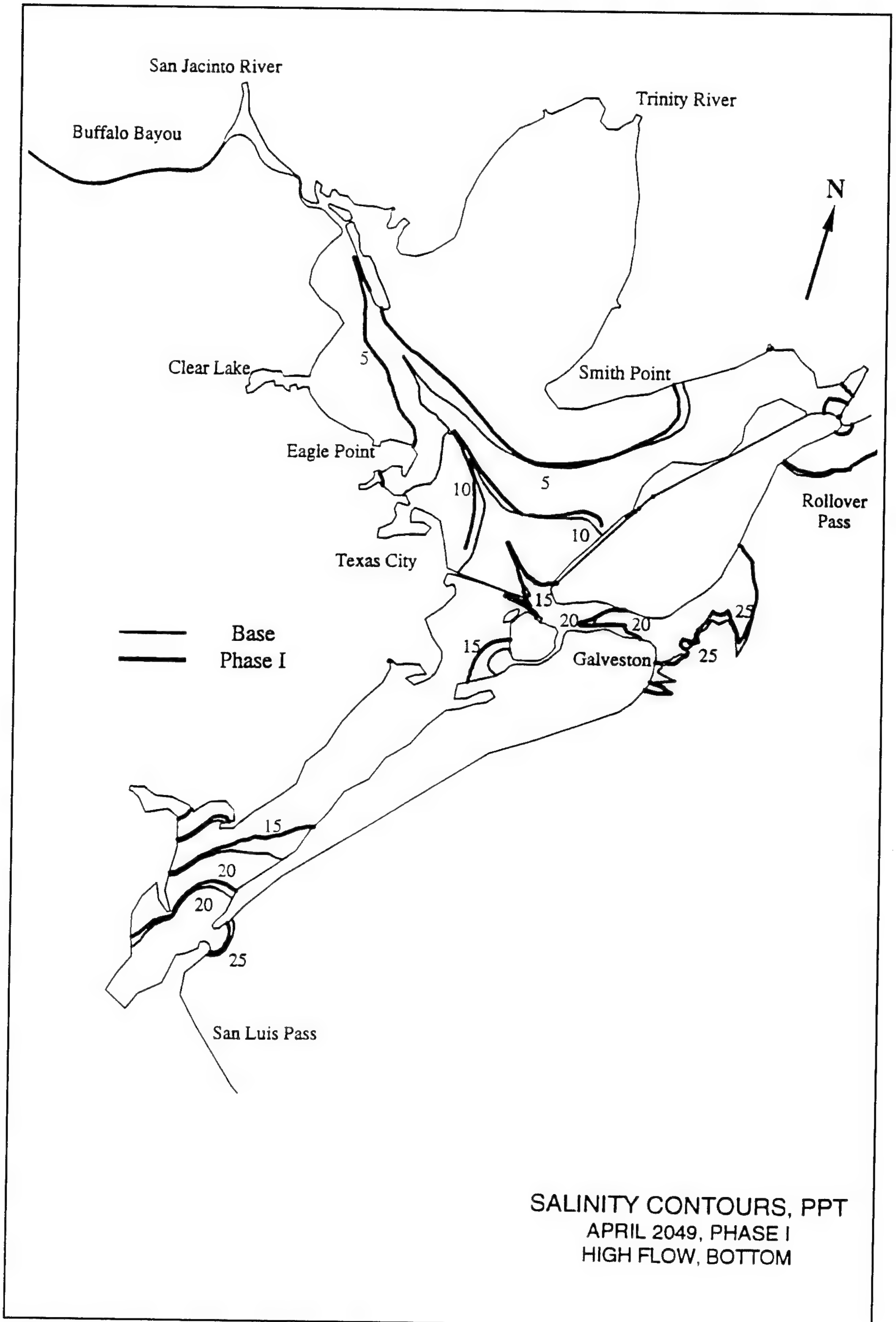


SALINITY CONTOURS, PPT
FEBRUARY 2049, PHASE I
HIGH FLOW, BOTTOM

Plate 364



SALINITY CONTOURS, PPT
MARCH 2049, PHASE I
HIGH FLOW, BOTTOM


San Jacinto River
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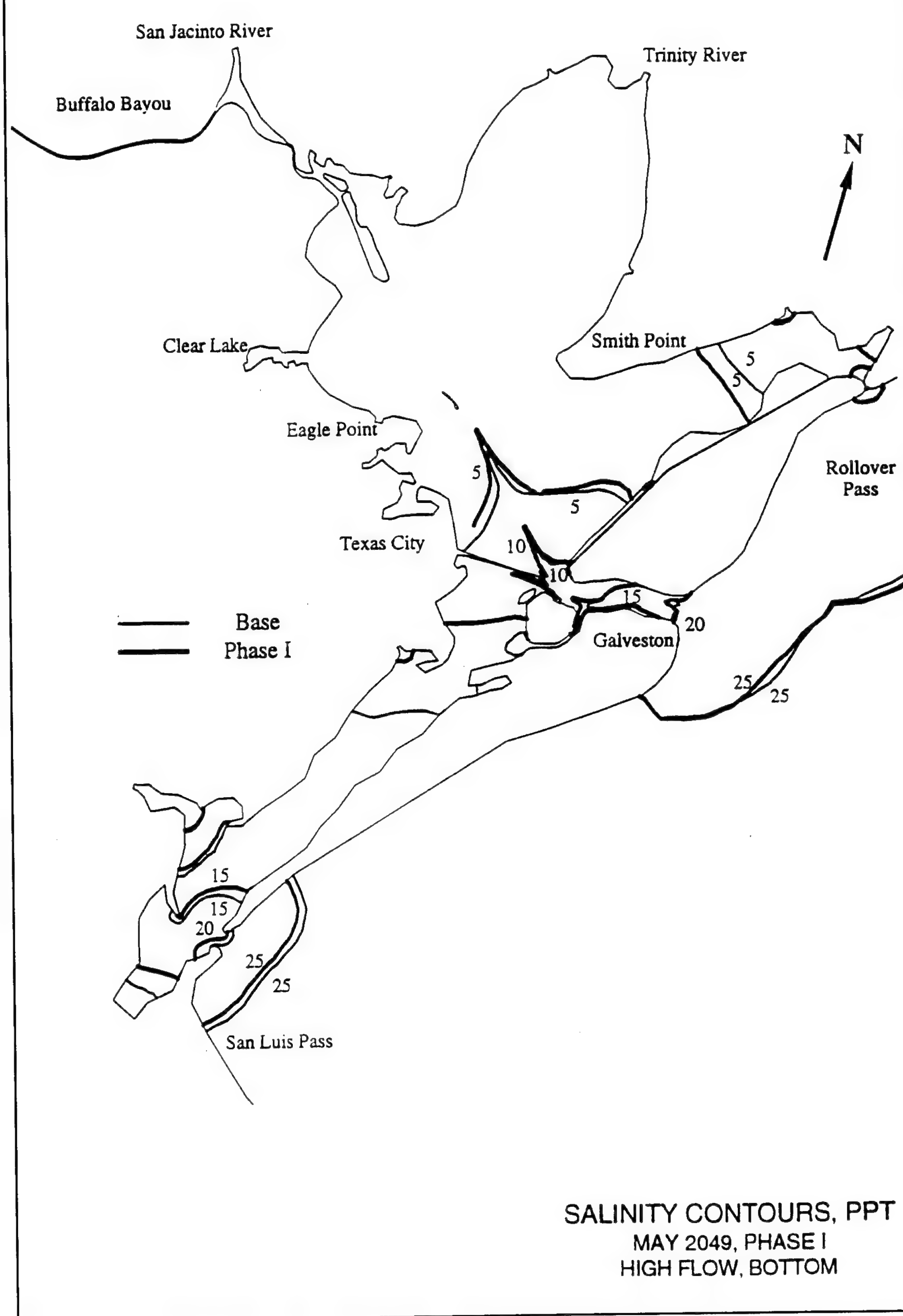
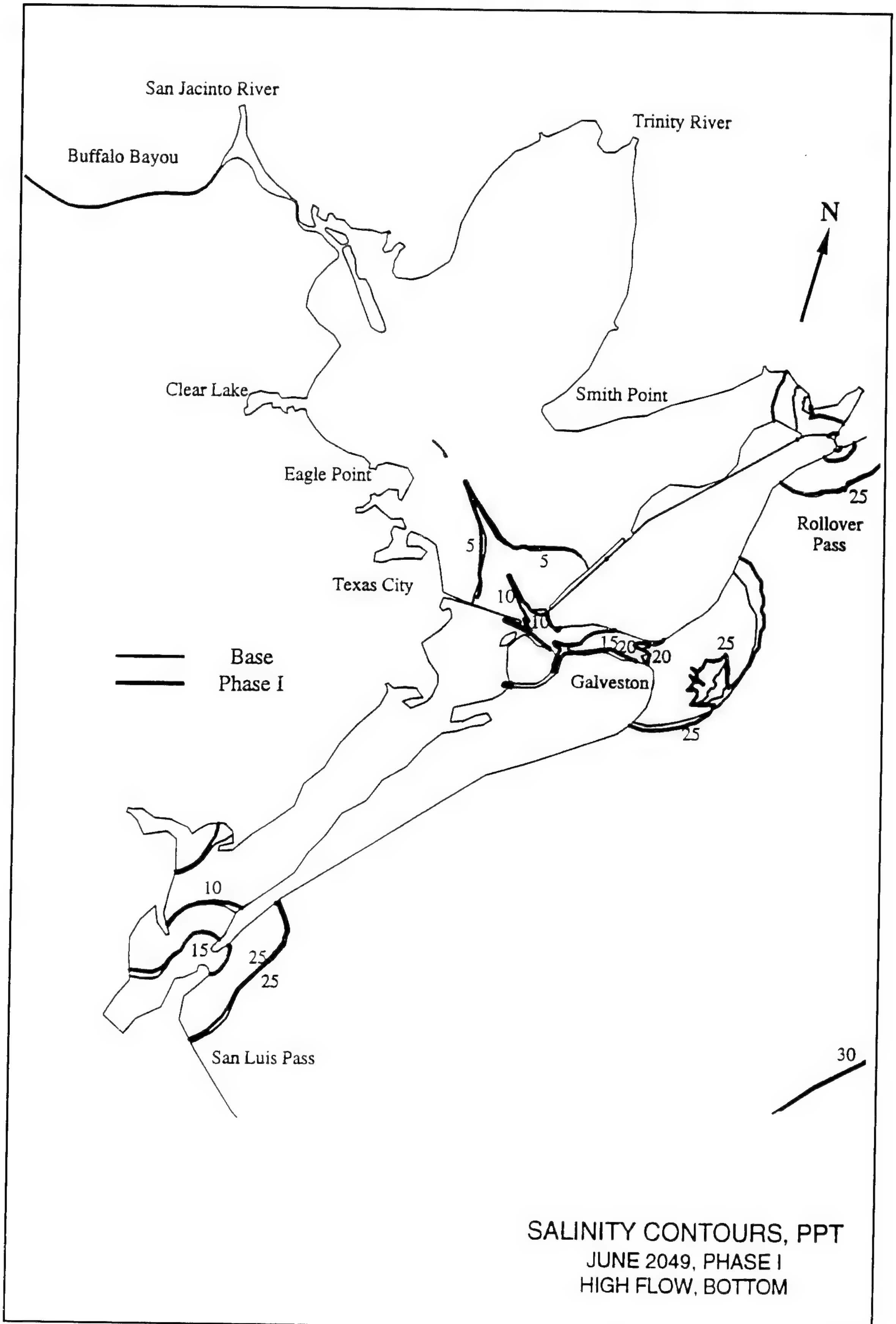
SALINITY CONTOURS, PPT
APRIL 2049, PHASE I
HIGH FLOW, BOTTOM

Plate 366



SALINITY CONTOURS, PPT
MAY 2049, PHASE I
HIGH FLOW, BOTTOM



San Jacinto River
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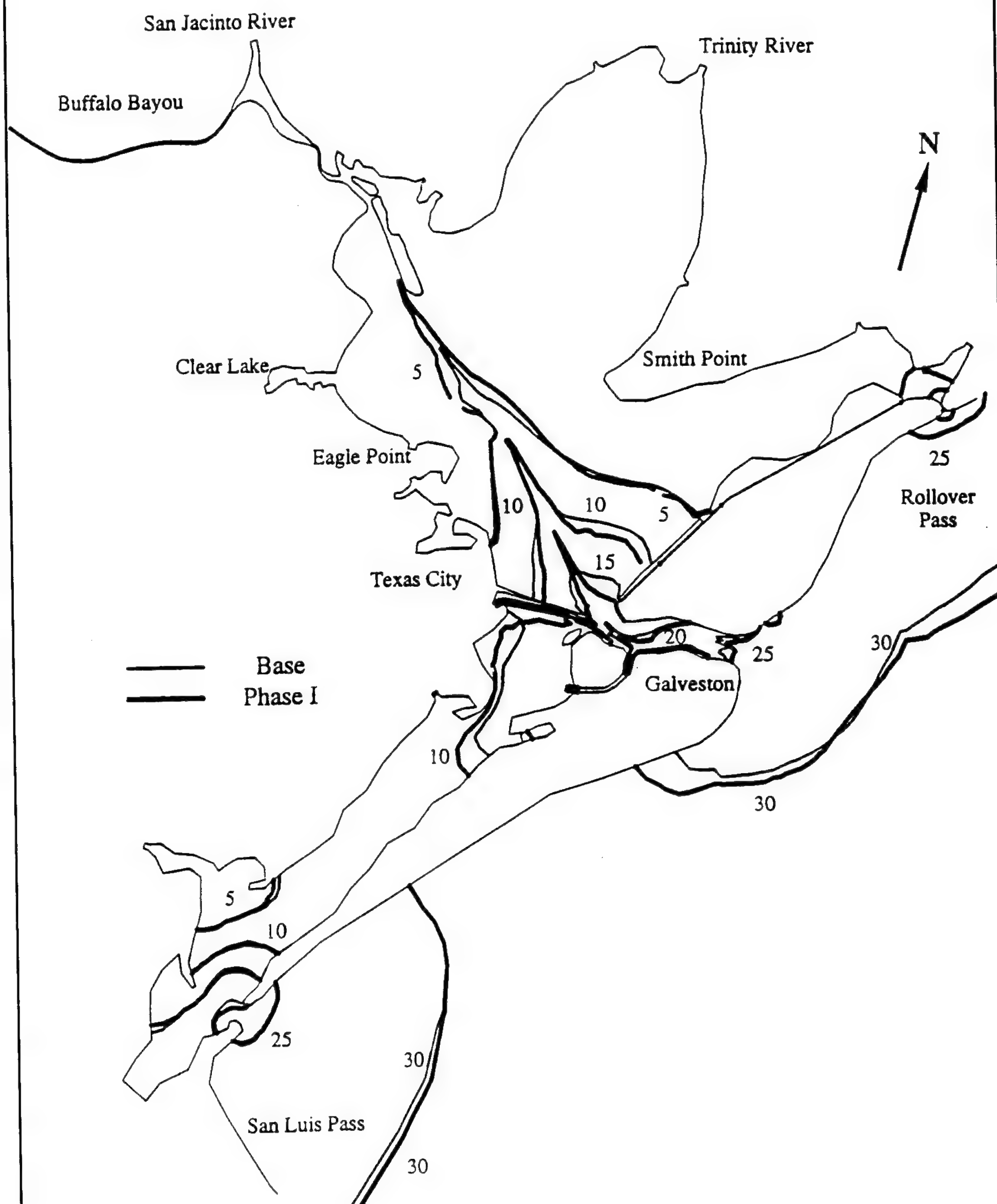
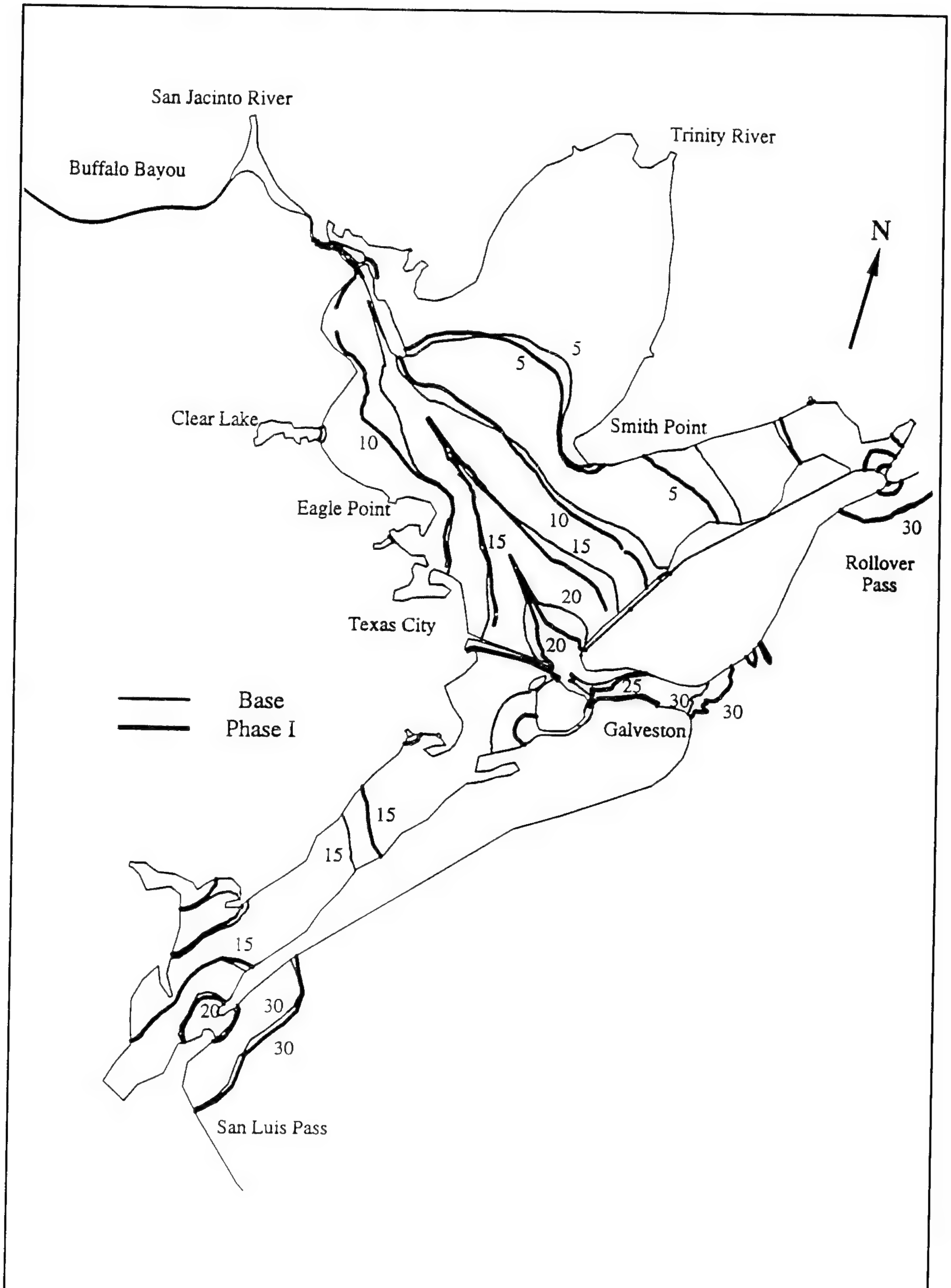
SALINITY CONTOURS, PPT
JUNE 2049, PHASE I
HIGH FLOW, BOTTOM

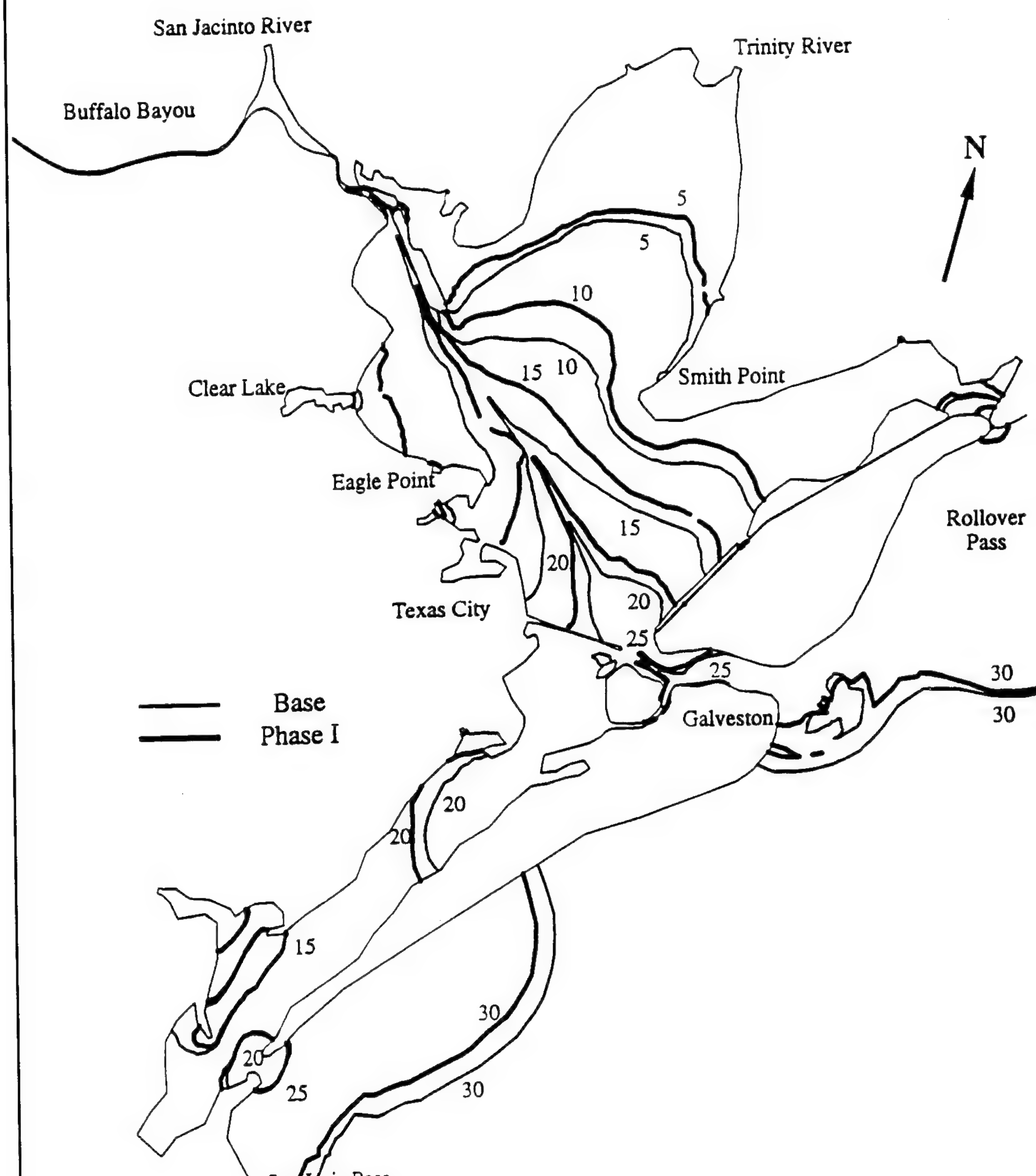
Plate 368



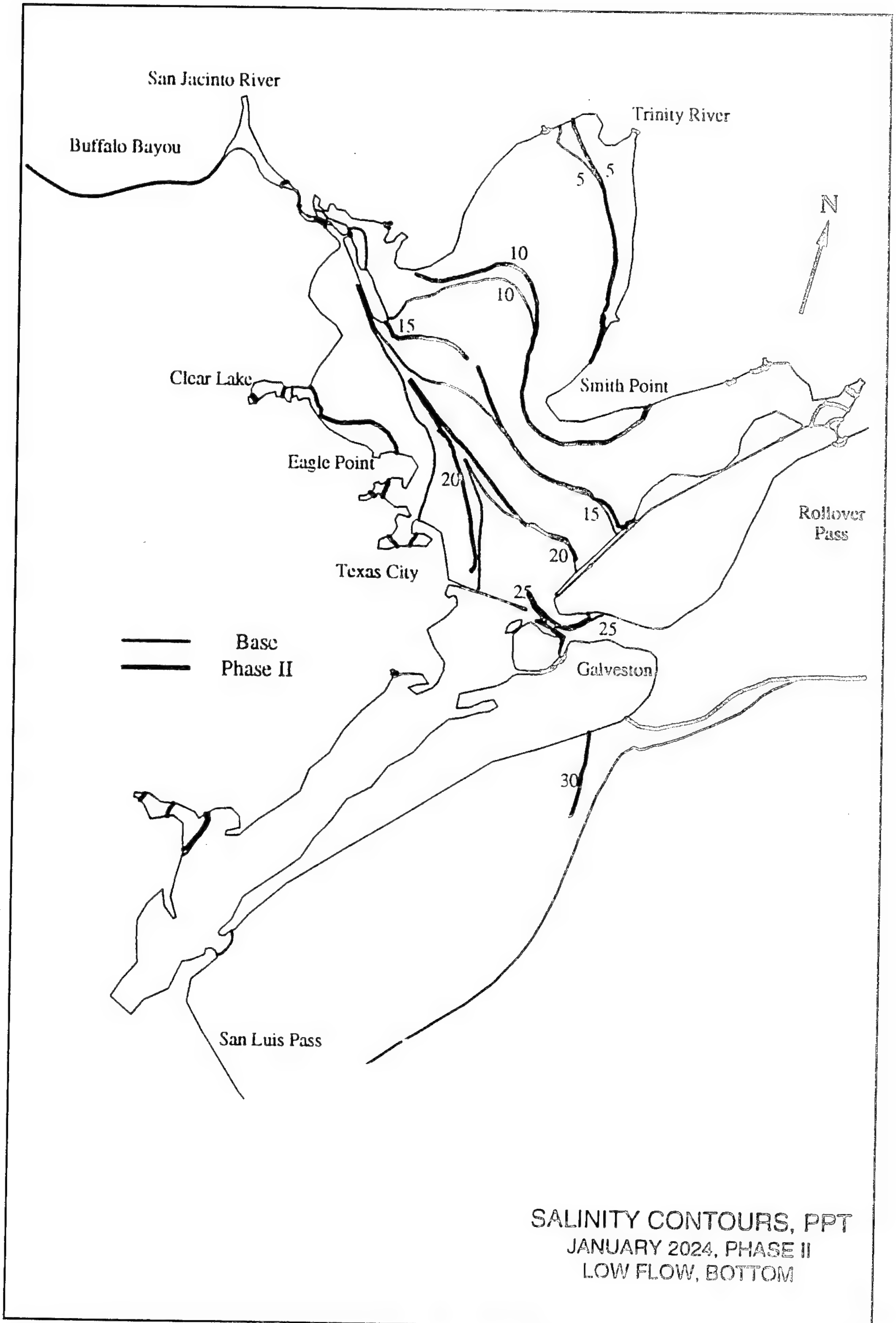
SALINITY CONTOURS, PPT
JULY 2049, PHASE I
HIGH FLOW, BOTTOM



SALINITY CONTOURS, PPT
AUGUST 2049, PHASE I
HIGH FLOW, BOTTOM



SALINITY CONTOURS, PPT
SEPTEMBER 2049, PHASE I
HIGH FLOW, BOTTOM



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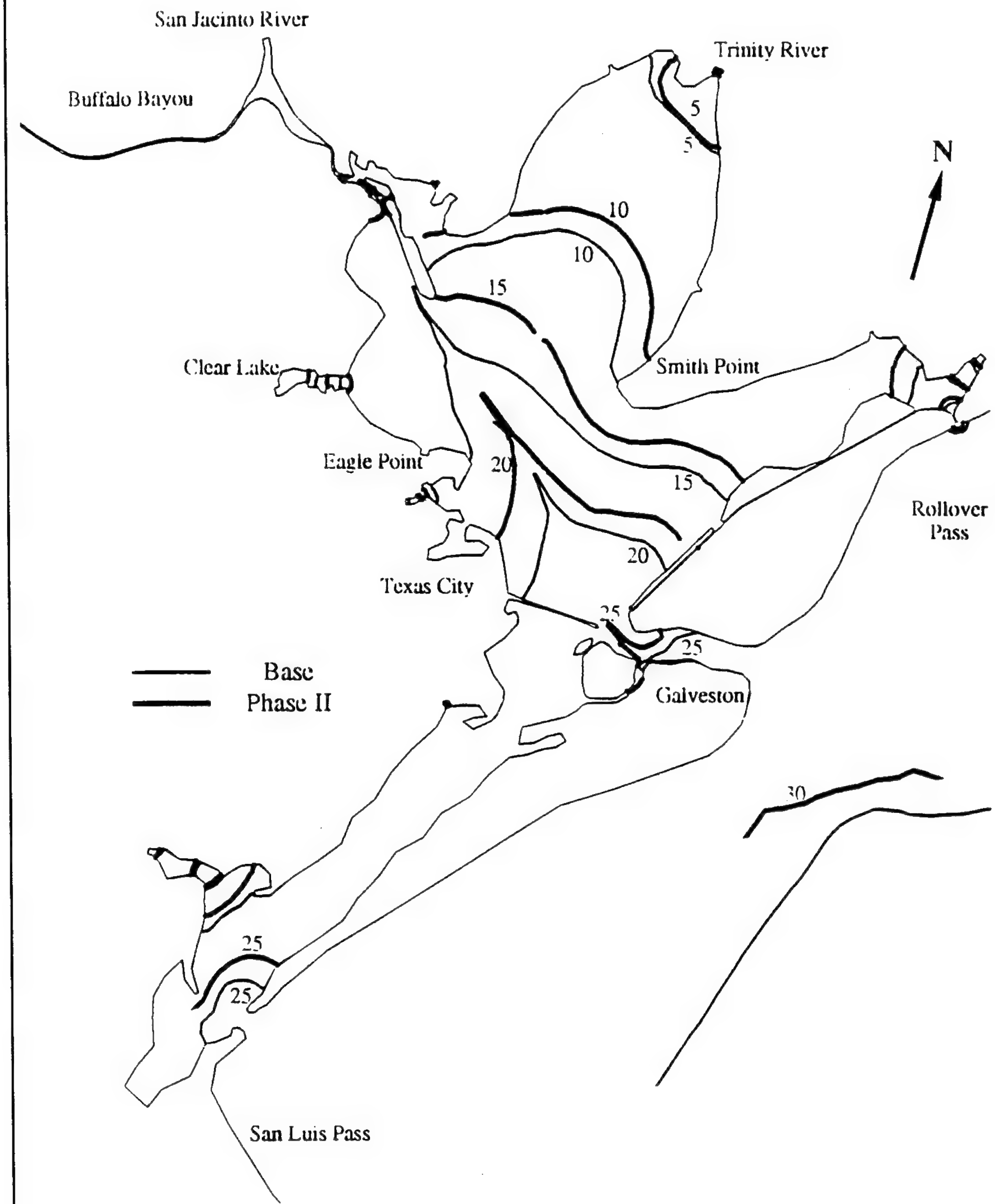
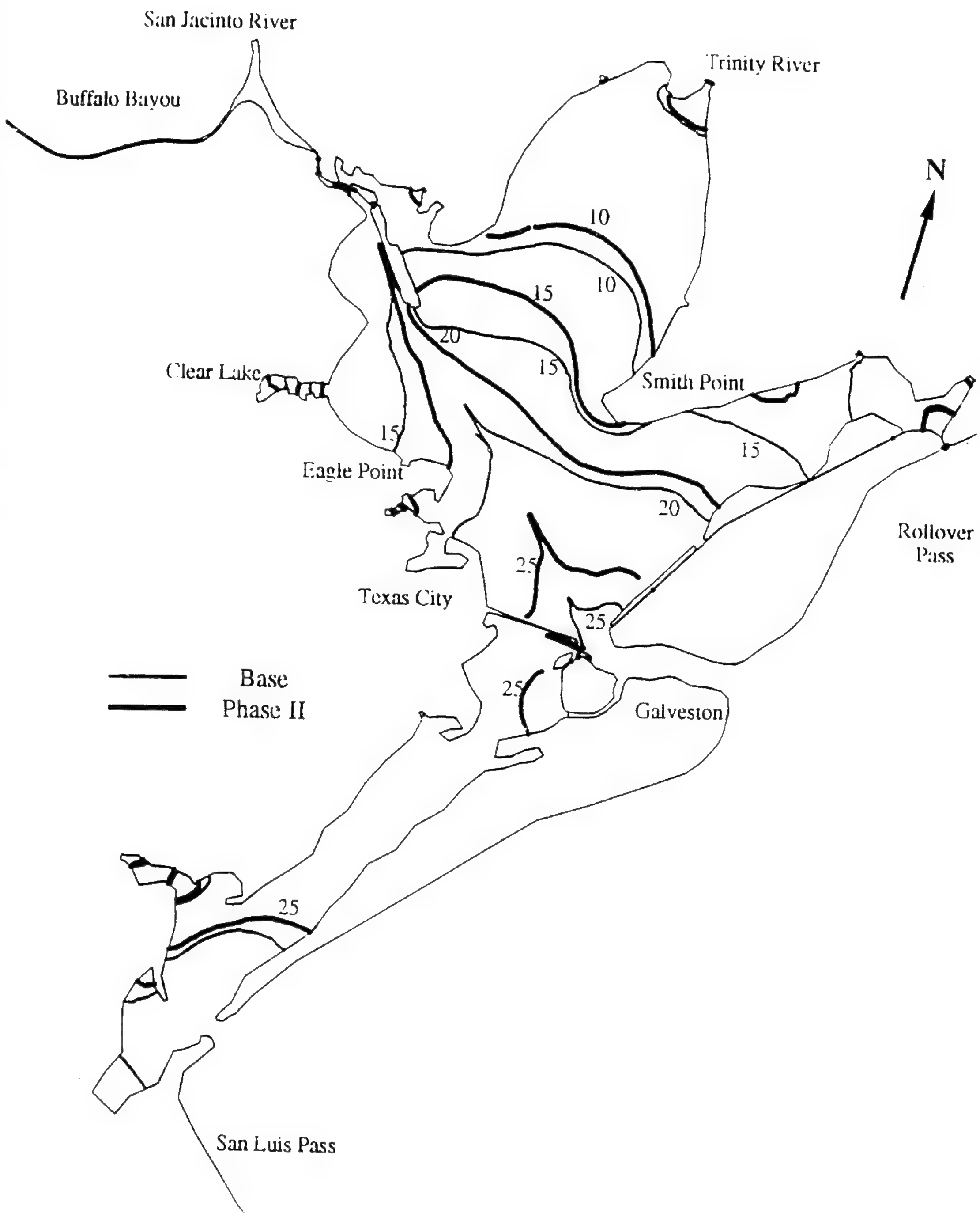
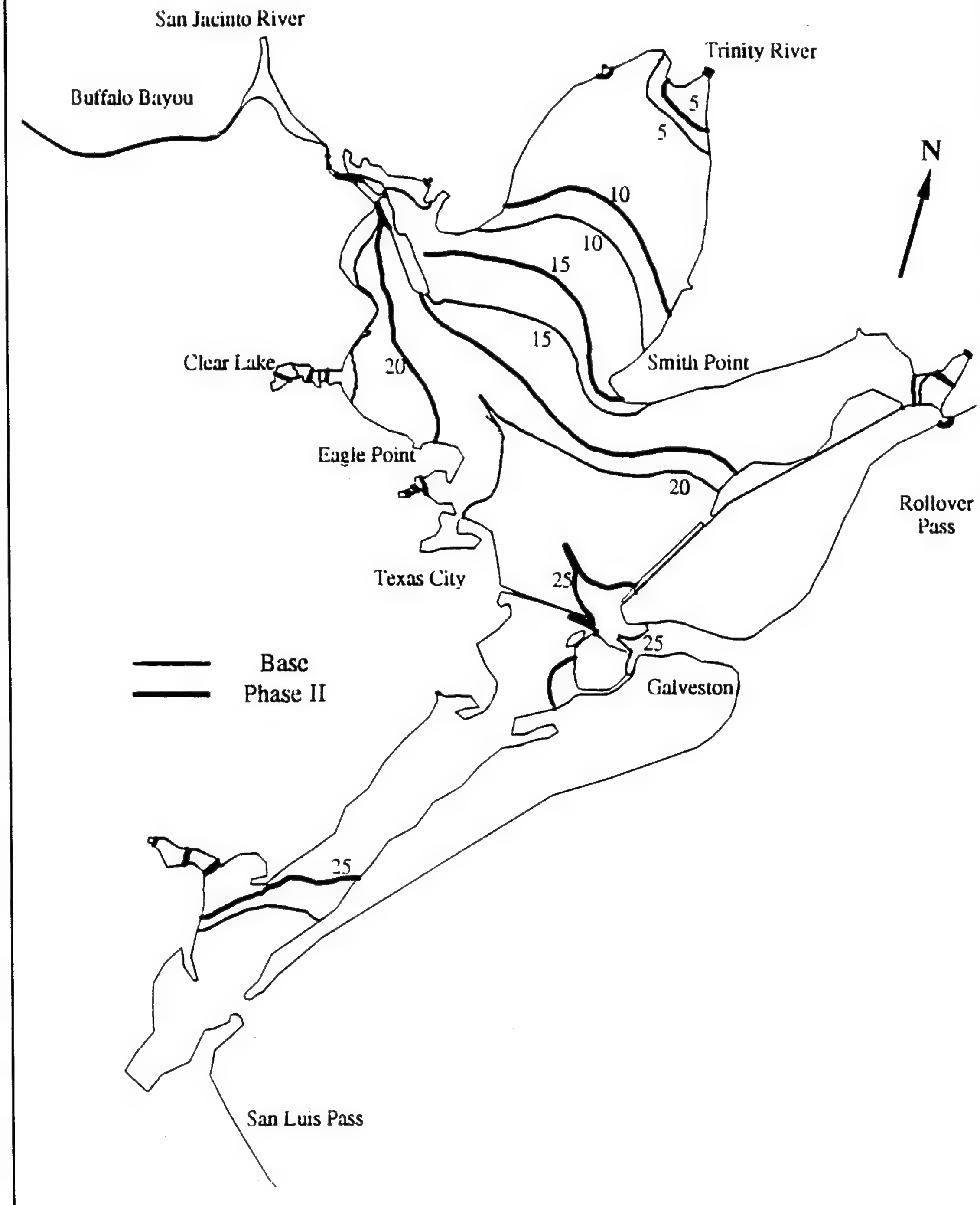
SALINITY CONTOURS, PPT
JANUARY 2024, PHASE II
LOW FLOW, BOTTOM



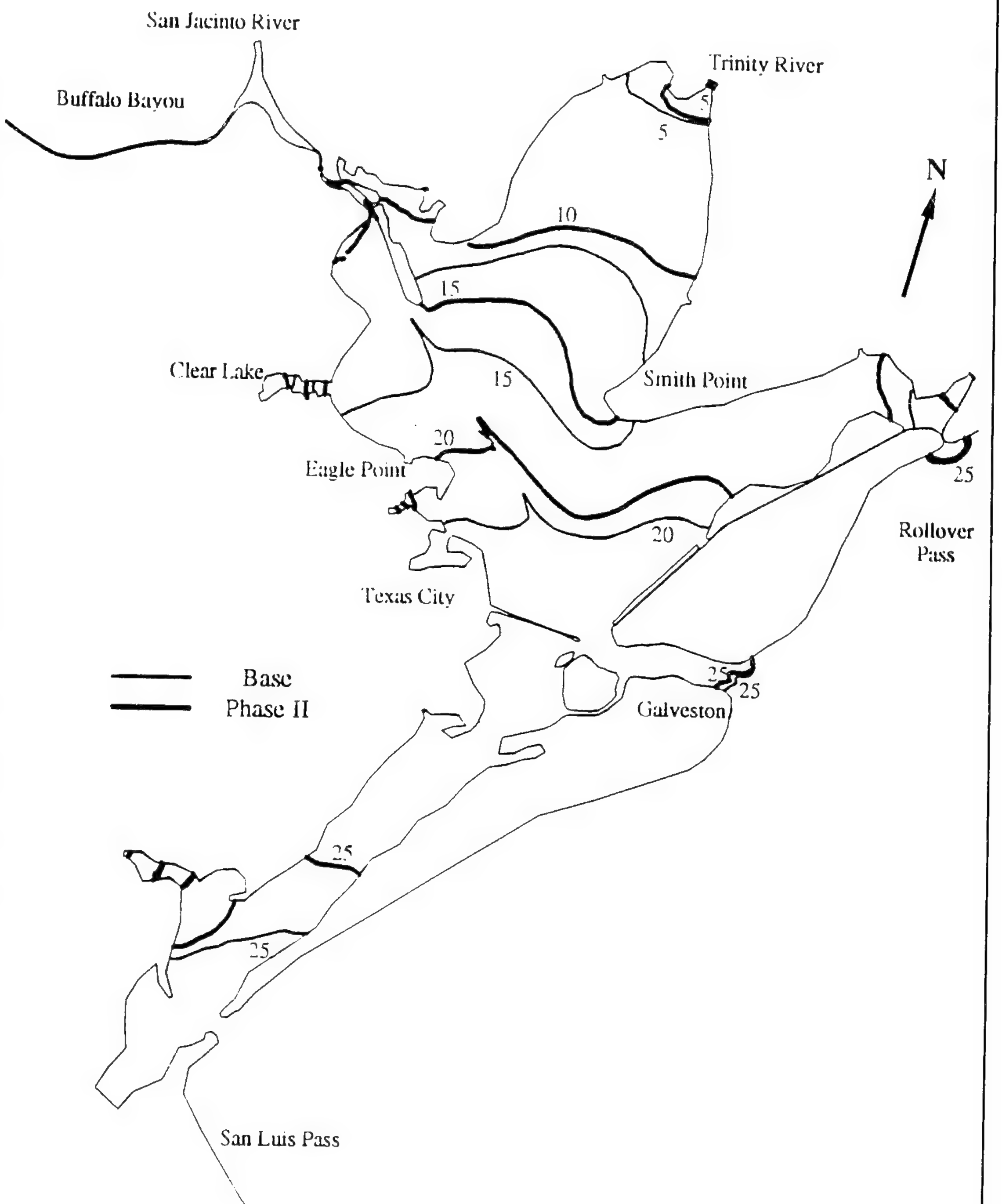
SALINITY CONTOURS, PPT
FEBRUARY 2024, PHASE II
LOW FLOW, BOTTOM



SALINITY CONTOURS, PPT
MARCH 2024, PHASE II
LOW FLOW, BOTTOM

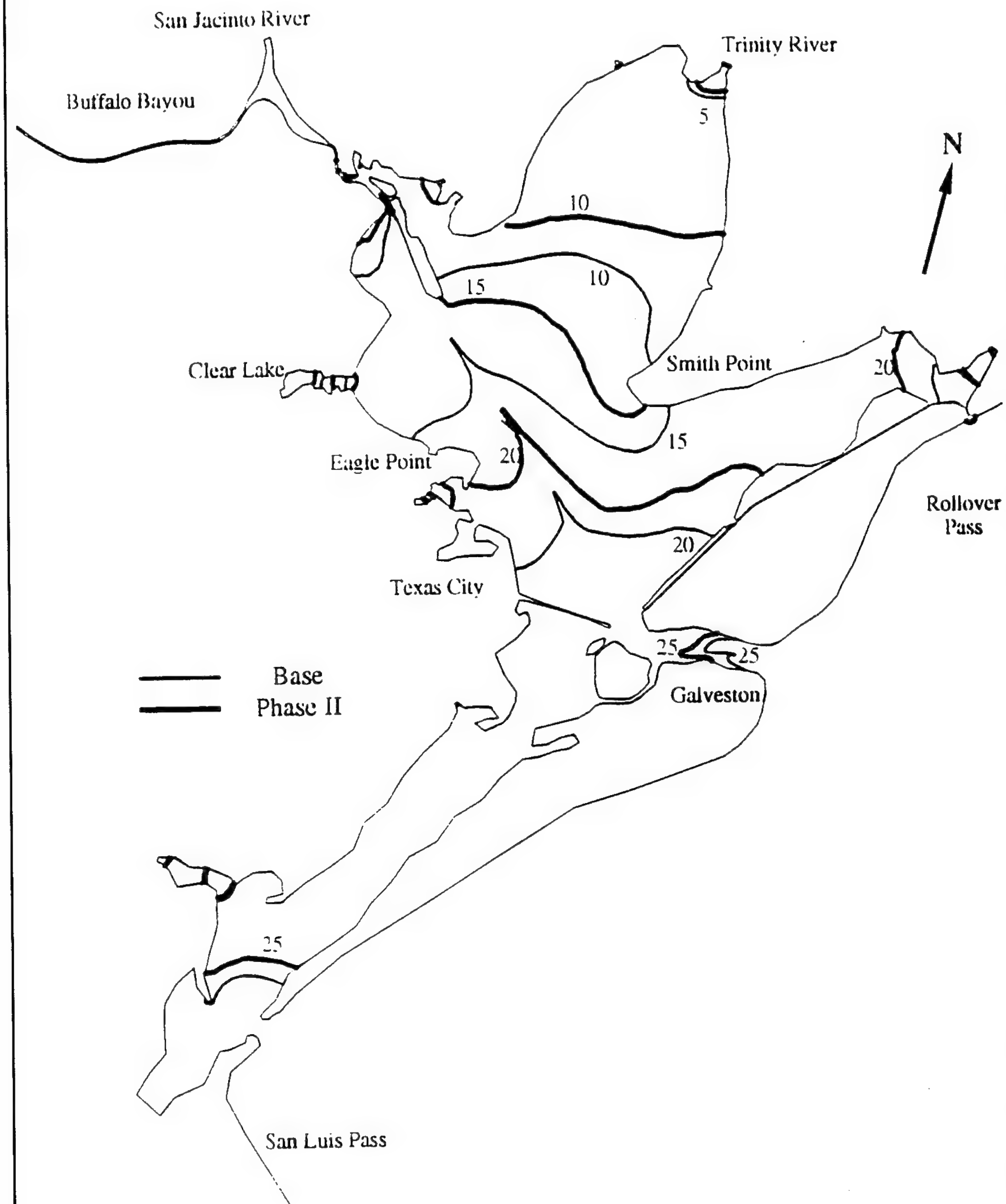


SALINITY CONTOURS, PPT
APRIL 2024, PHASE II
LOW FLOW, BOTTOM

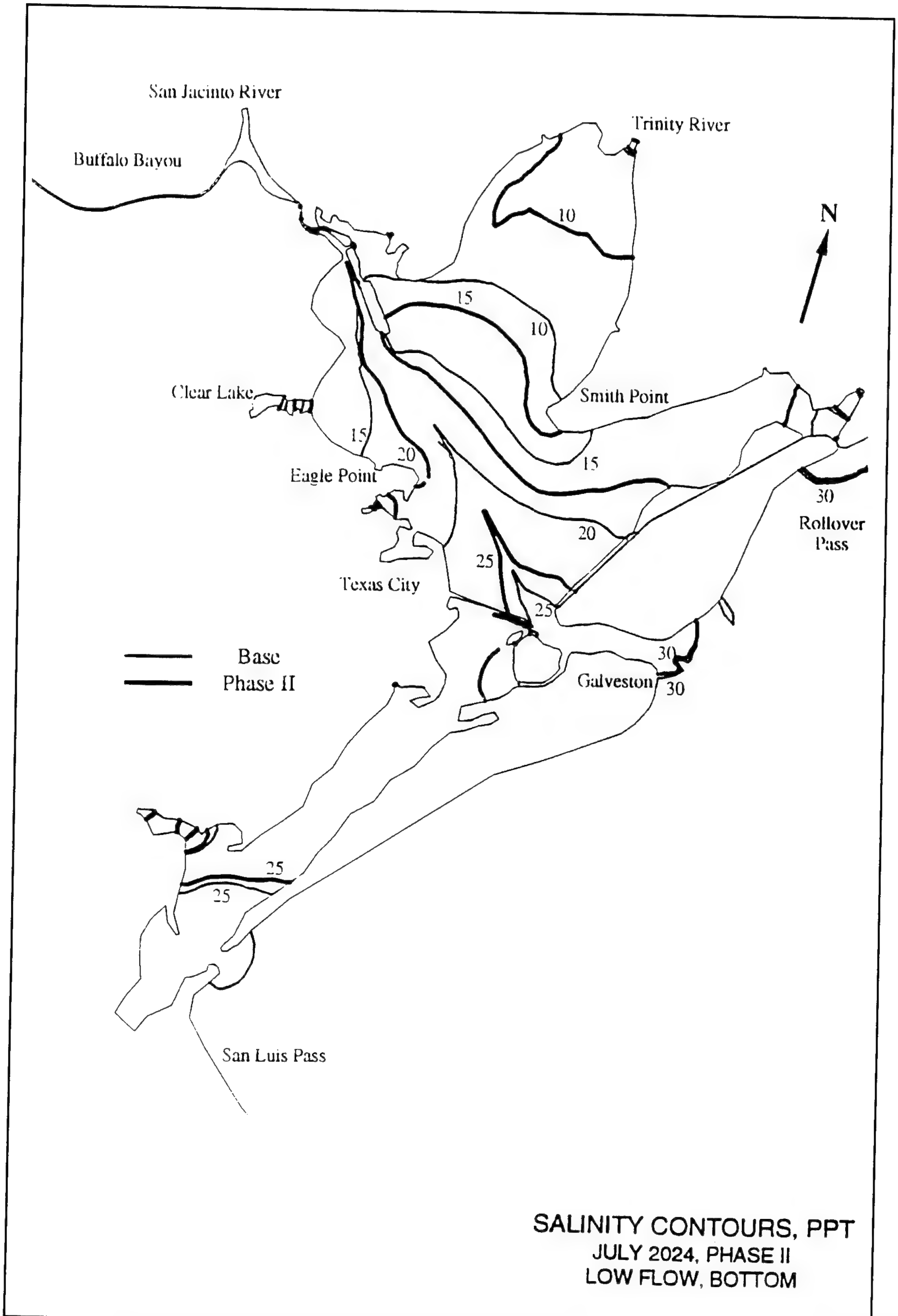


SALINITY CONTOURS, PPT
MAY 2024, PHASE II
LOW FLOW, BOTTOM

Plate 376



SALINITY CONTOURS, PPT
JUNE 2024, PHASE II
LOW FLOW, BOTTOM


San Jacinto River
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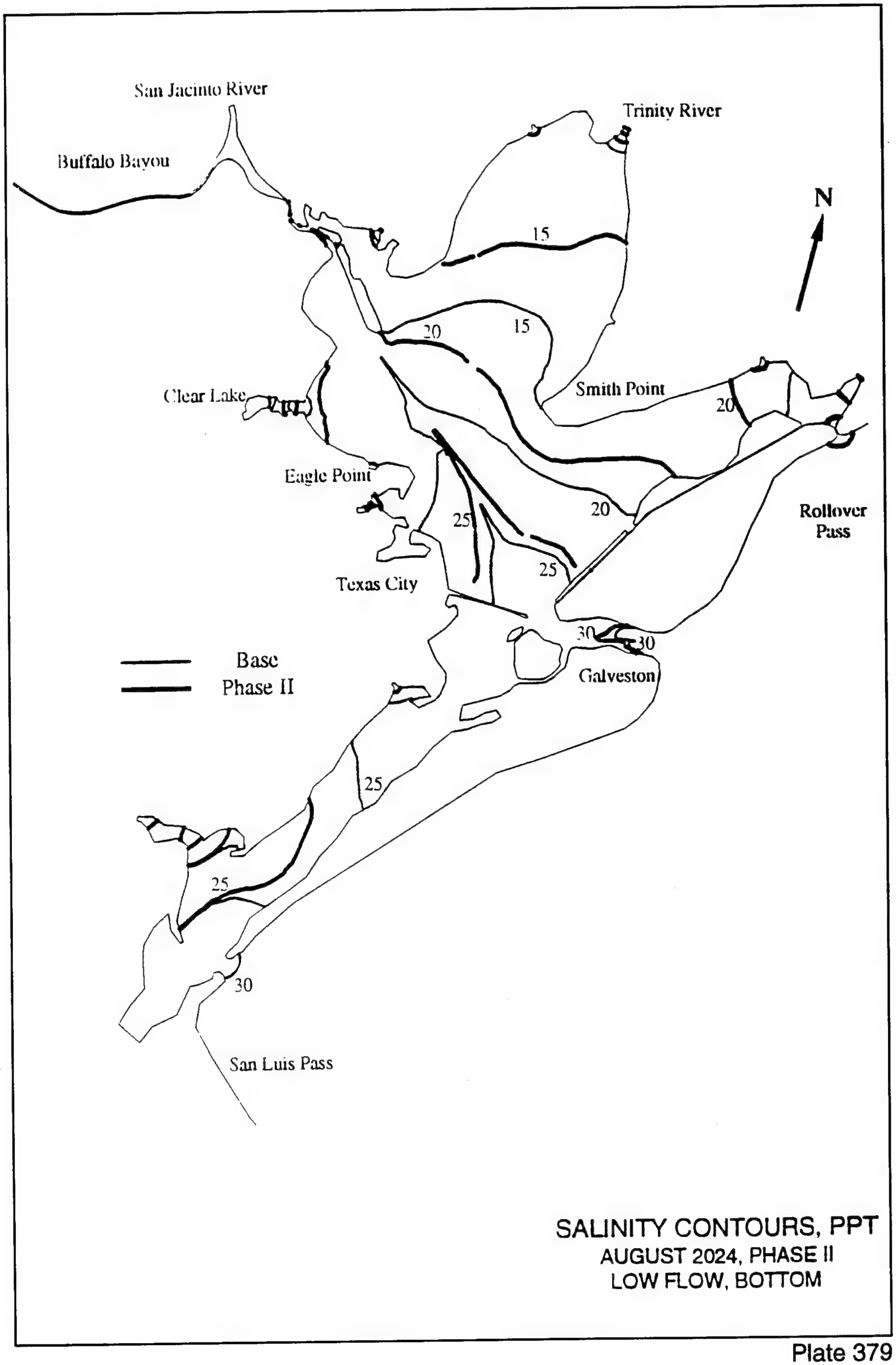
SALINITY CONTOURS, PPT
JULY 2024, PHASE II
LOW FLOW, BOTTOM



San Jacinto River
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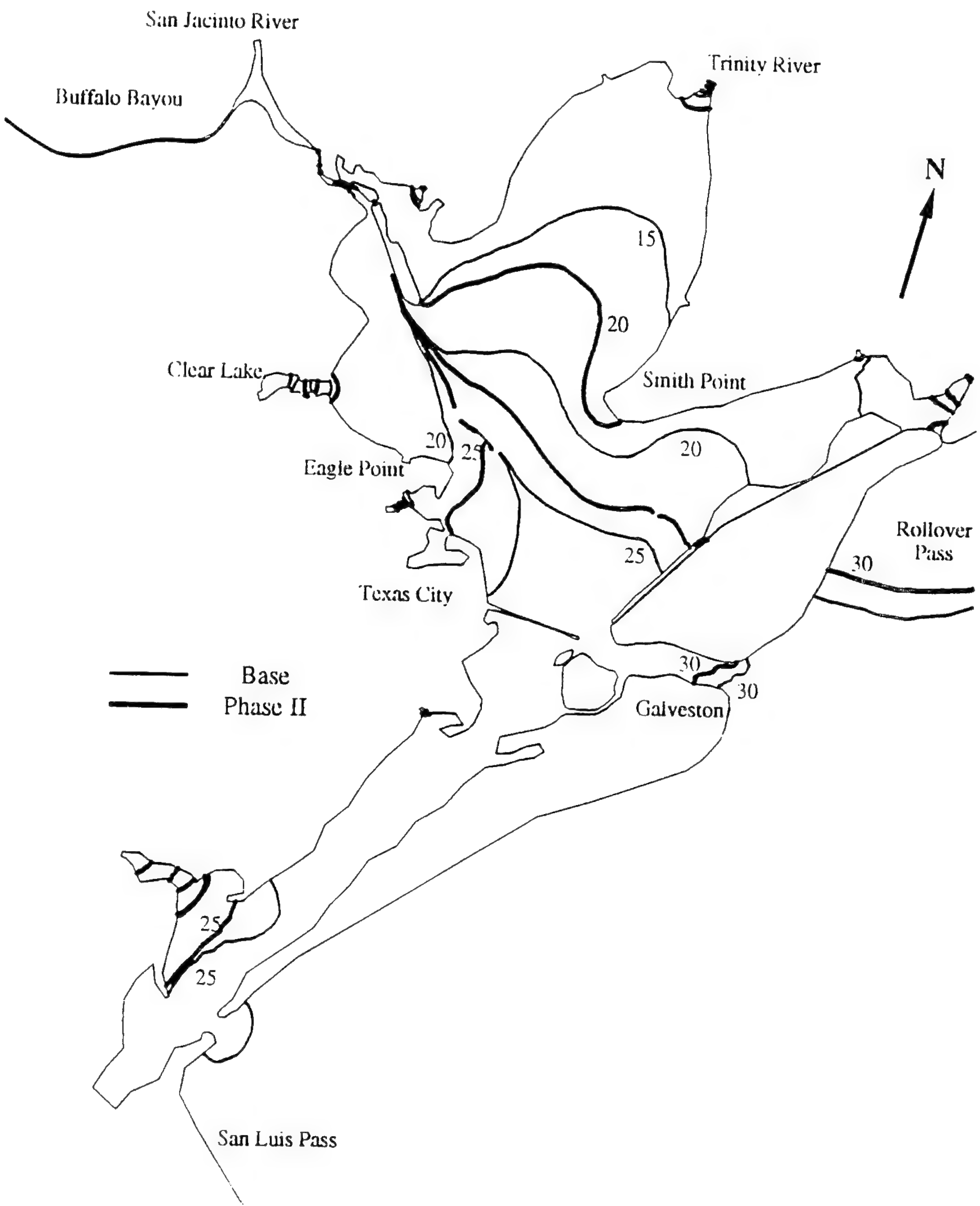
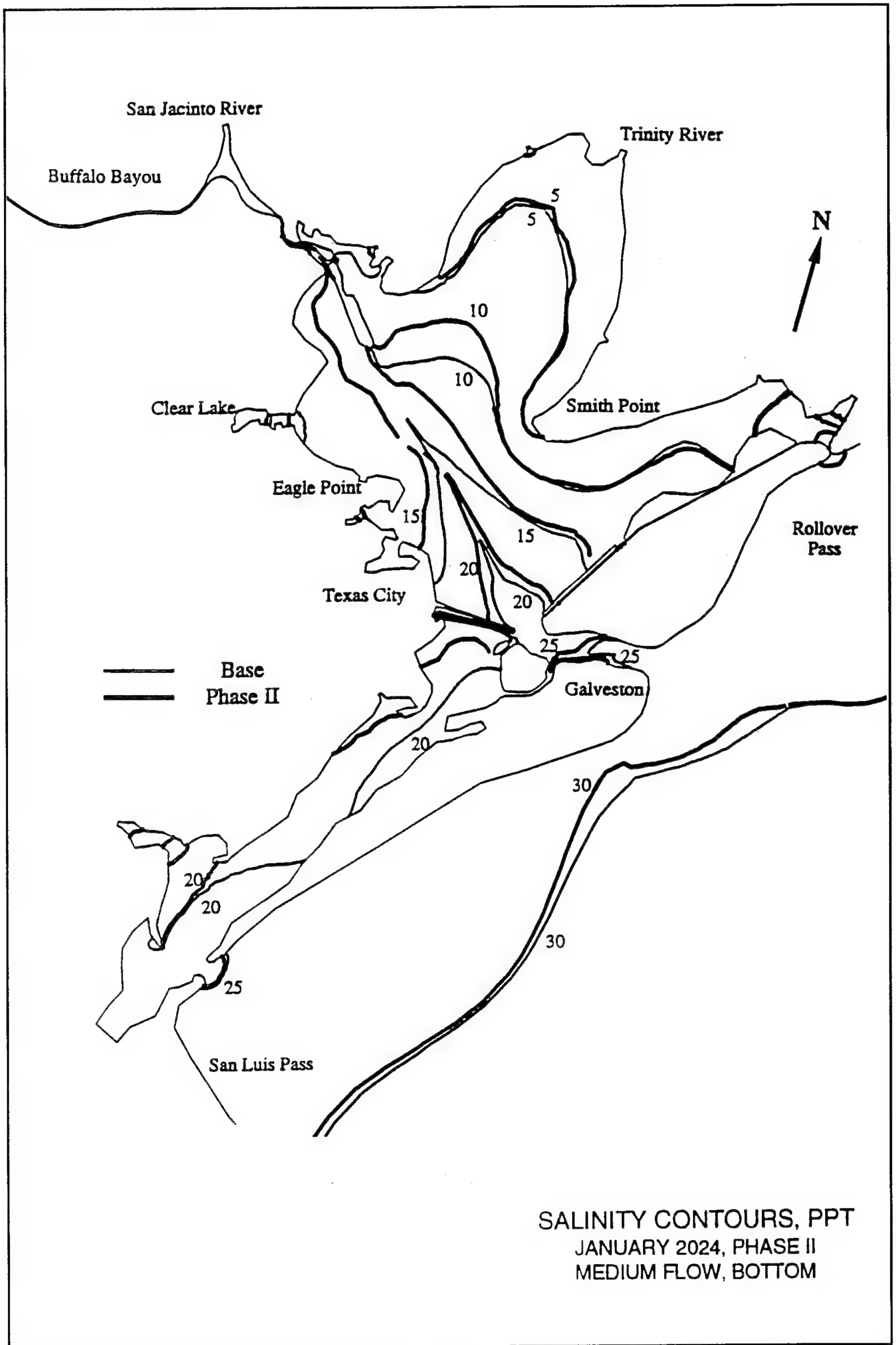
SALINITY CONTOURS, PPT
AUGUST 2024, PHASE II
LOW FLOW, BOTTOM



SALINITY CONTOURS, PPT
SEPTEMBER 2024, PHASE II
LOW FLOW, BOTTOM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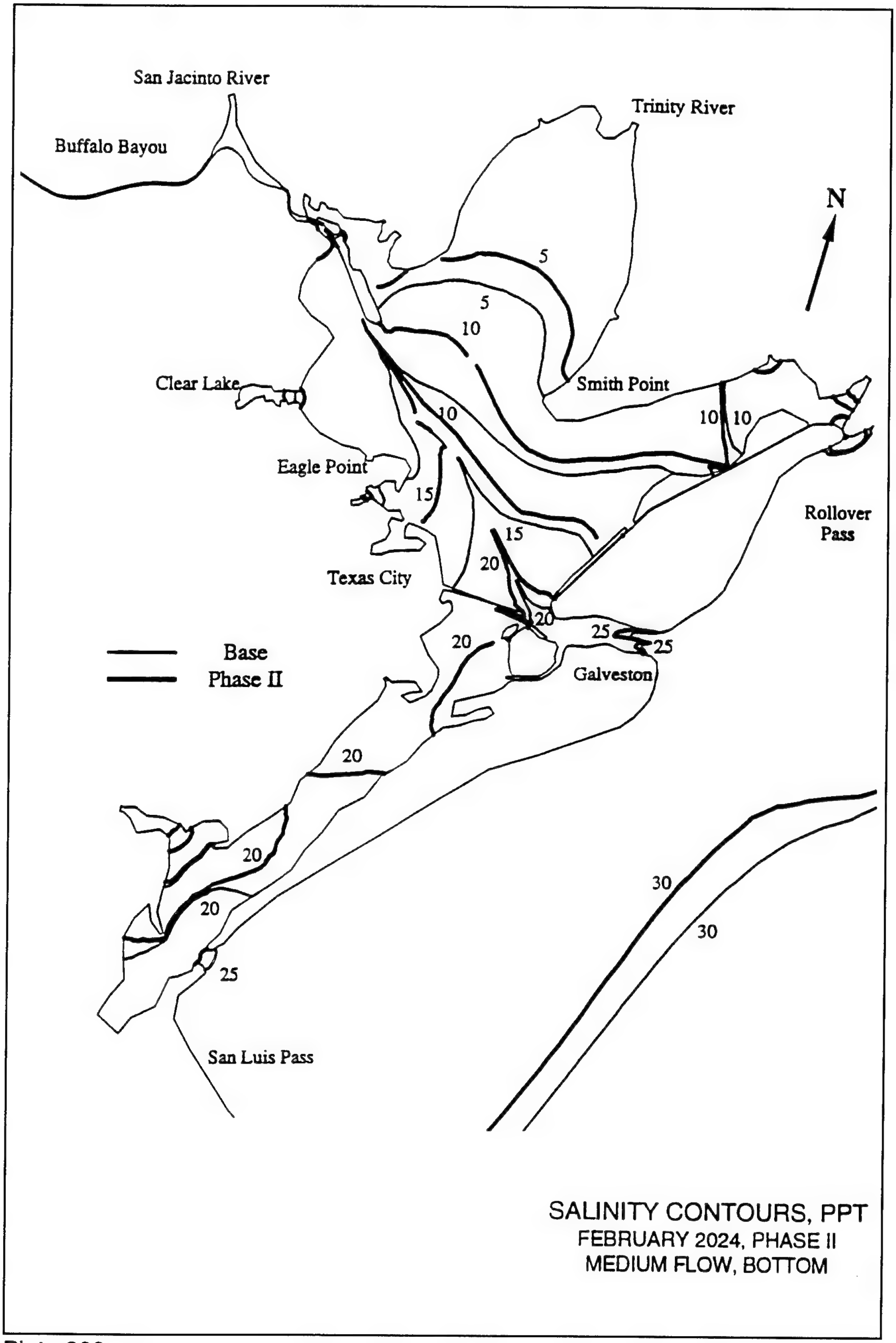
SALINITY CONTOURS, PPT
JANUARY 2024, PHASE II
MEDIUM FLOW, BOTTOM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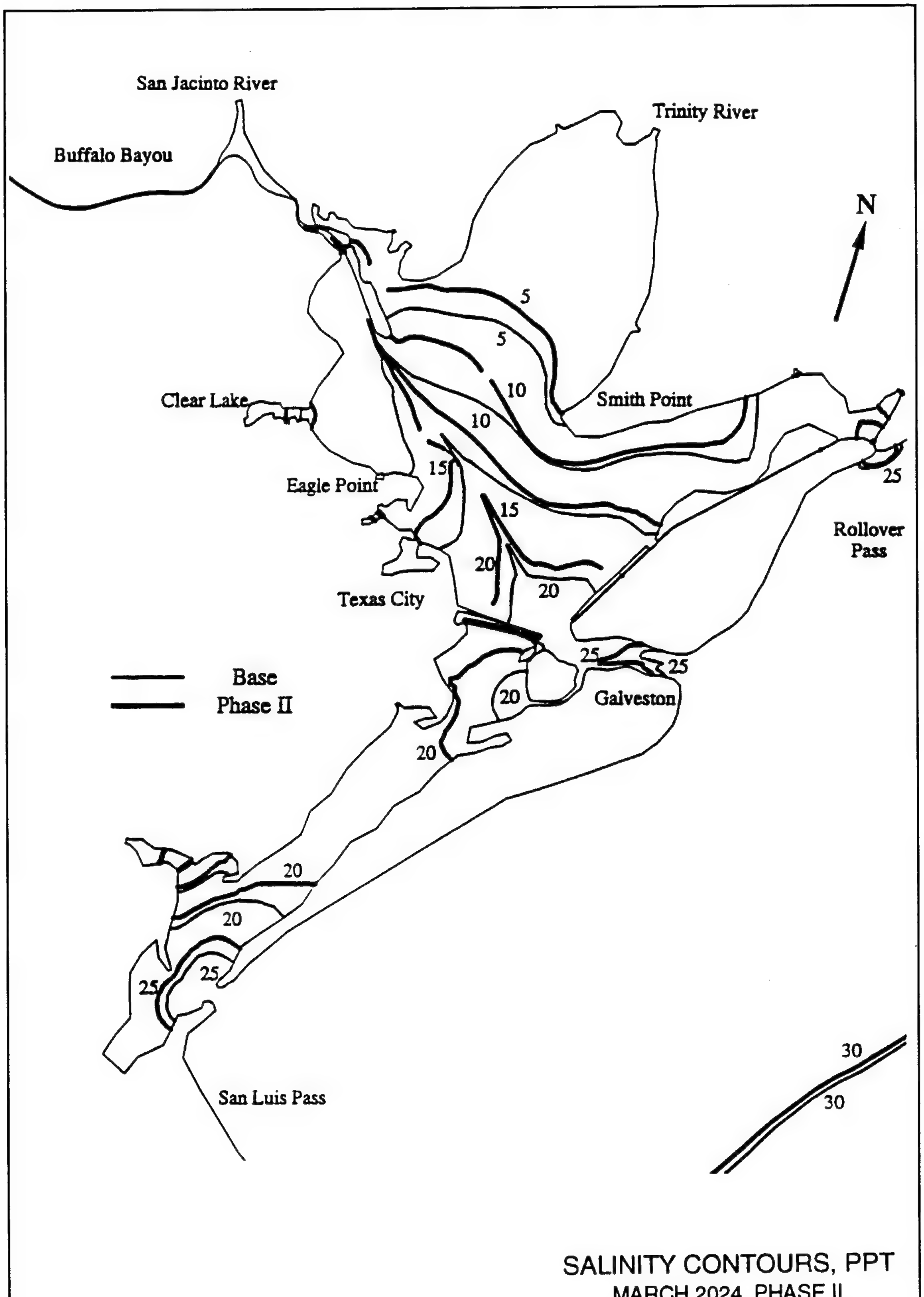
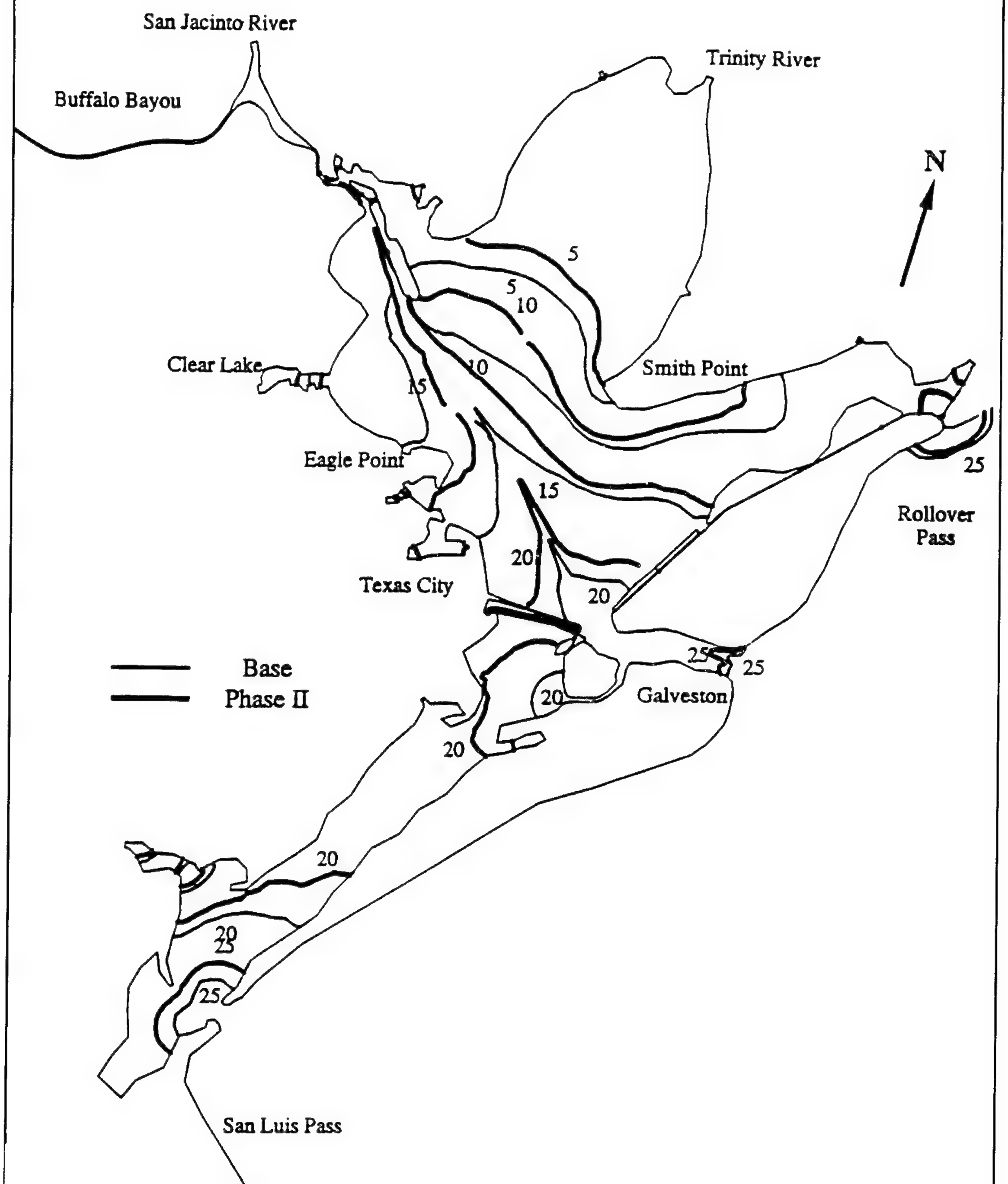
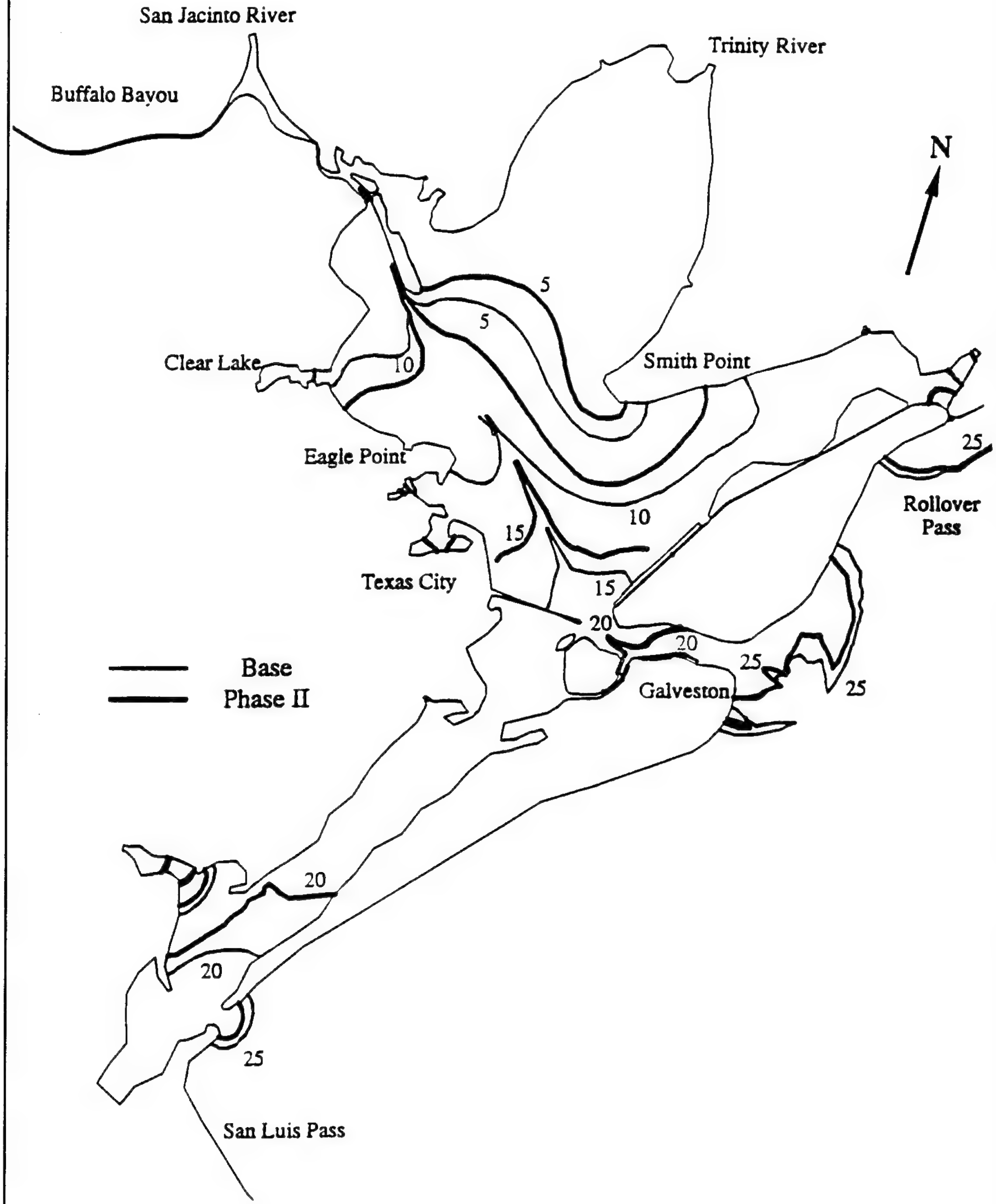
SALINITY CONTOURS, PPT
FEBRUARY 2024, PHASE II
MEDIUM FLOW, BOTTOM



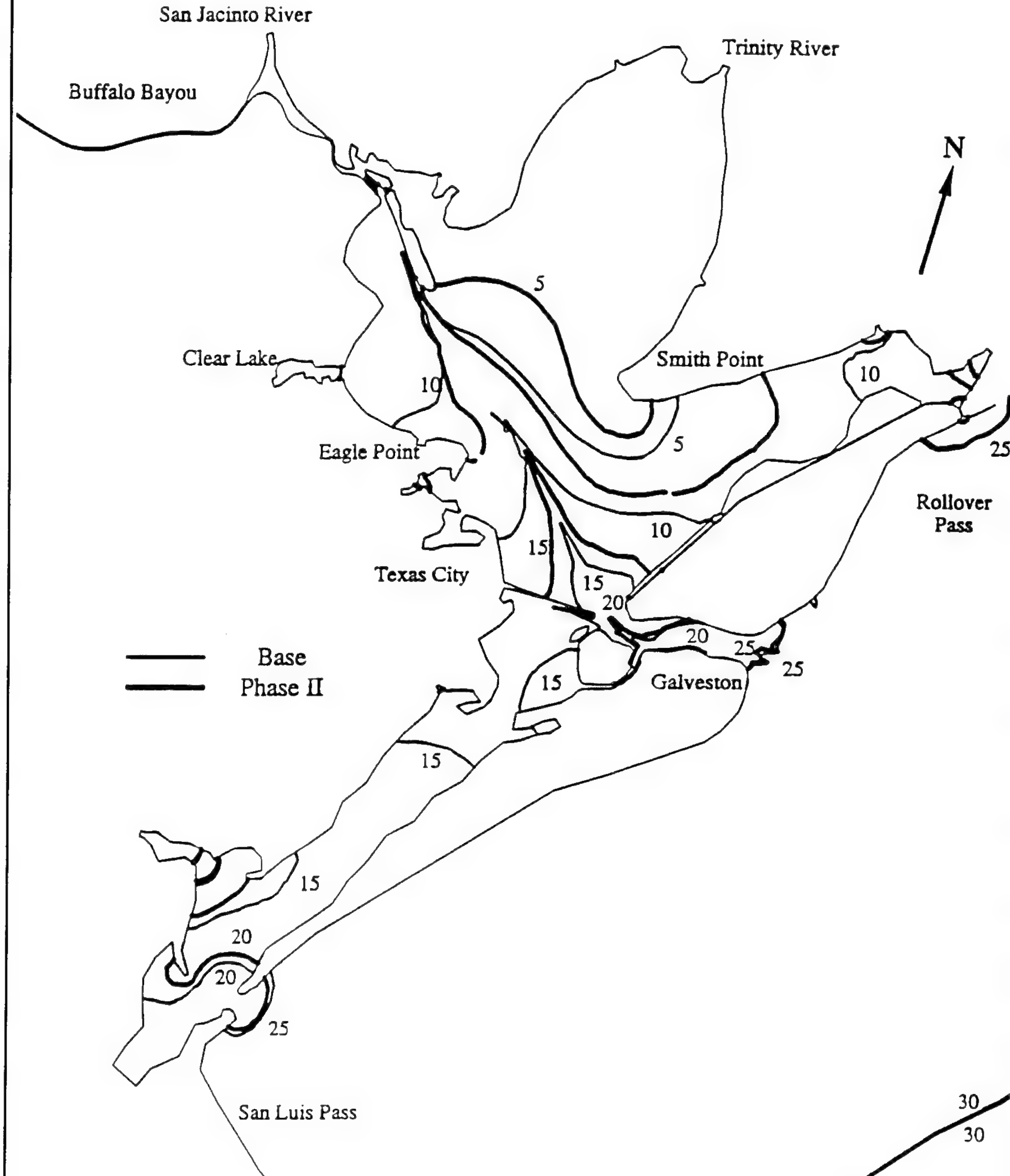
SALINITY CONTOURS, PPT
MARCH 2024, PHASE II
MEDIUM FLOW, BOTTOM



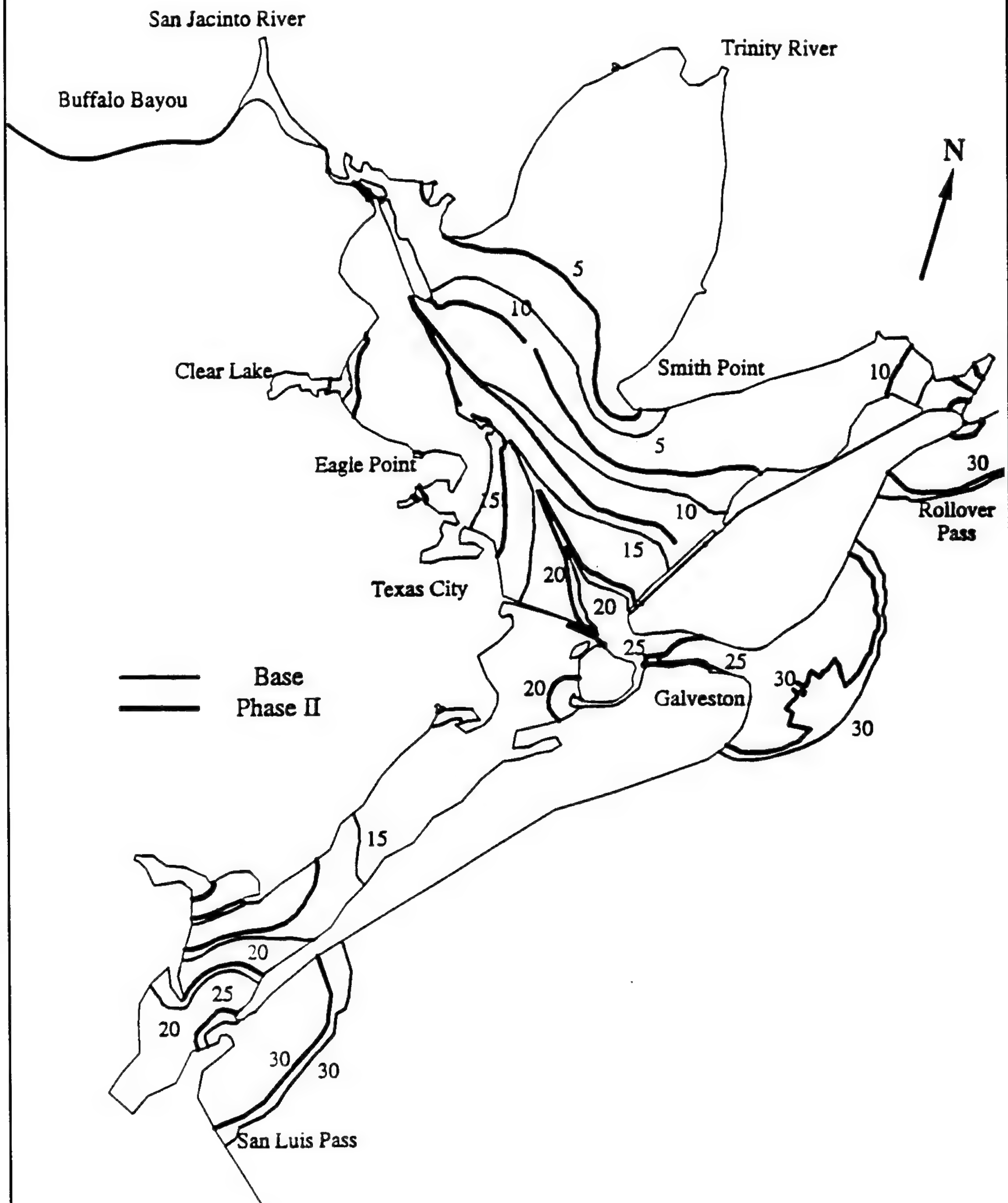
SALINITY CONTOURS, PPT
APRIL 2024, PHASE II
MEDIUM FLOW, BOTTOM



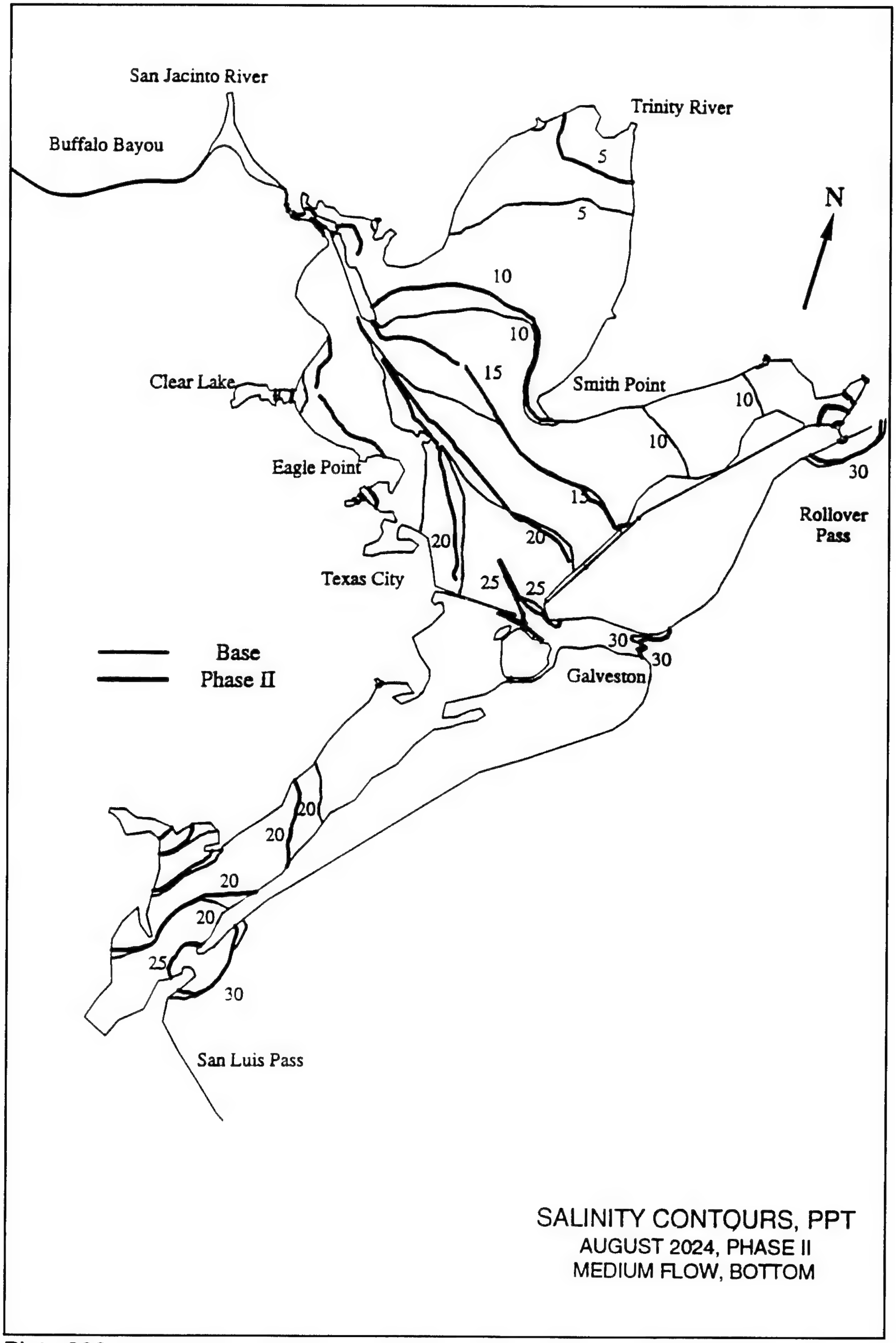
SALINITY CONTOURS, PPT
MAY 2024, PHASE II
MEDIUM FLOW, BOTTOM



SALINITY CONTOURS, PPT
JUNE 2024, PHASE II
MEDIUM FLOW, BOTTOM



SALINITY CONTOURS, PPT
JULY 2024, PHASE II
MEDIUM FLOW, BOTTOM


San Jacinto River
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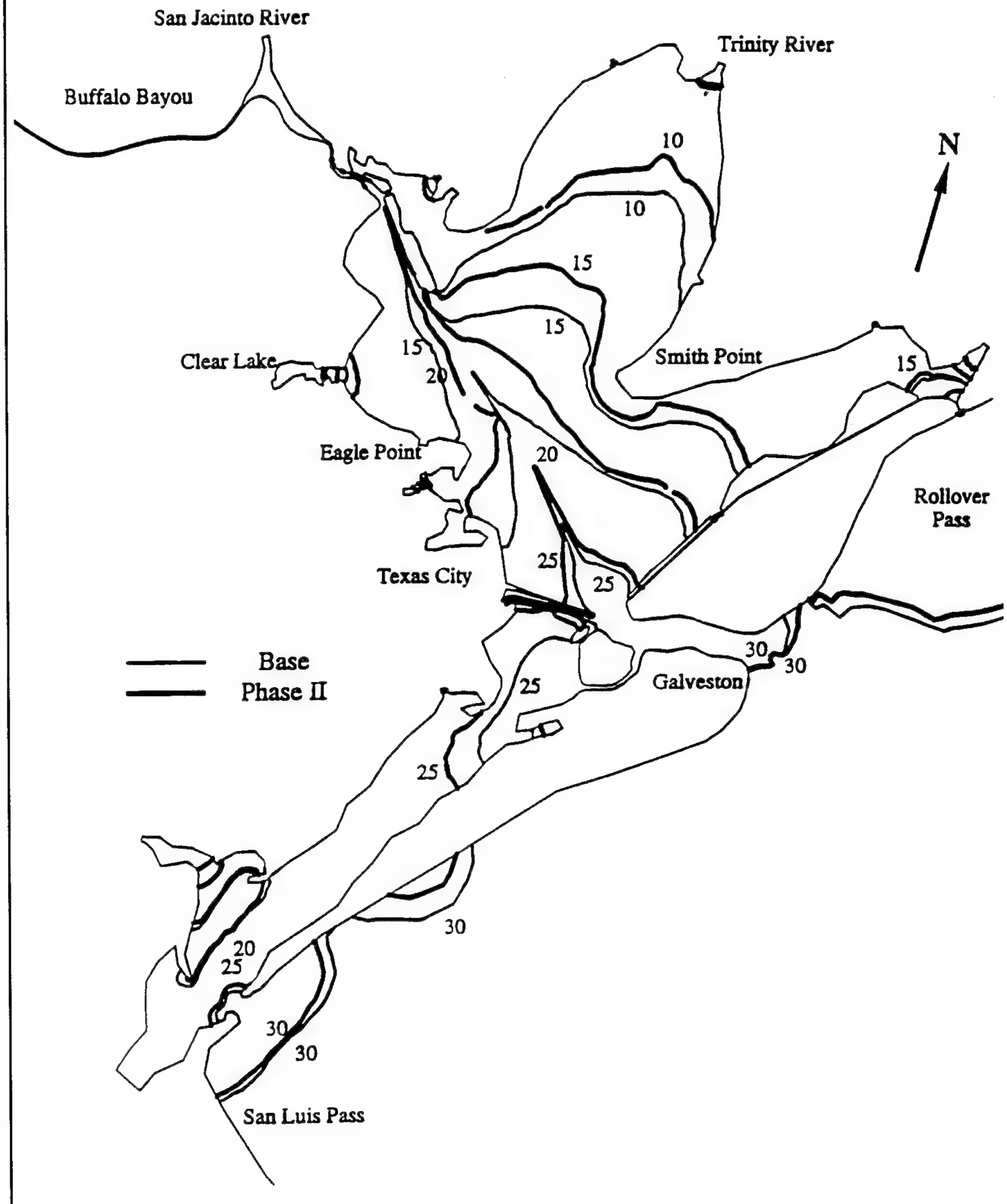
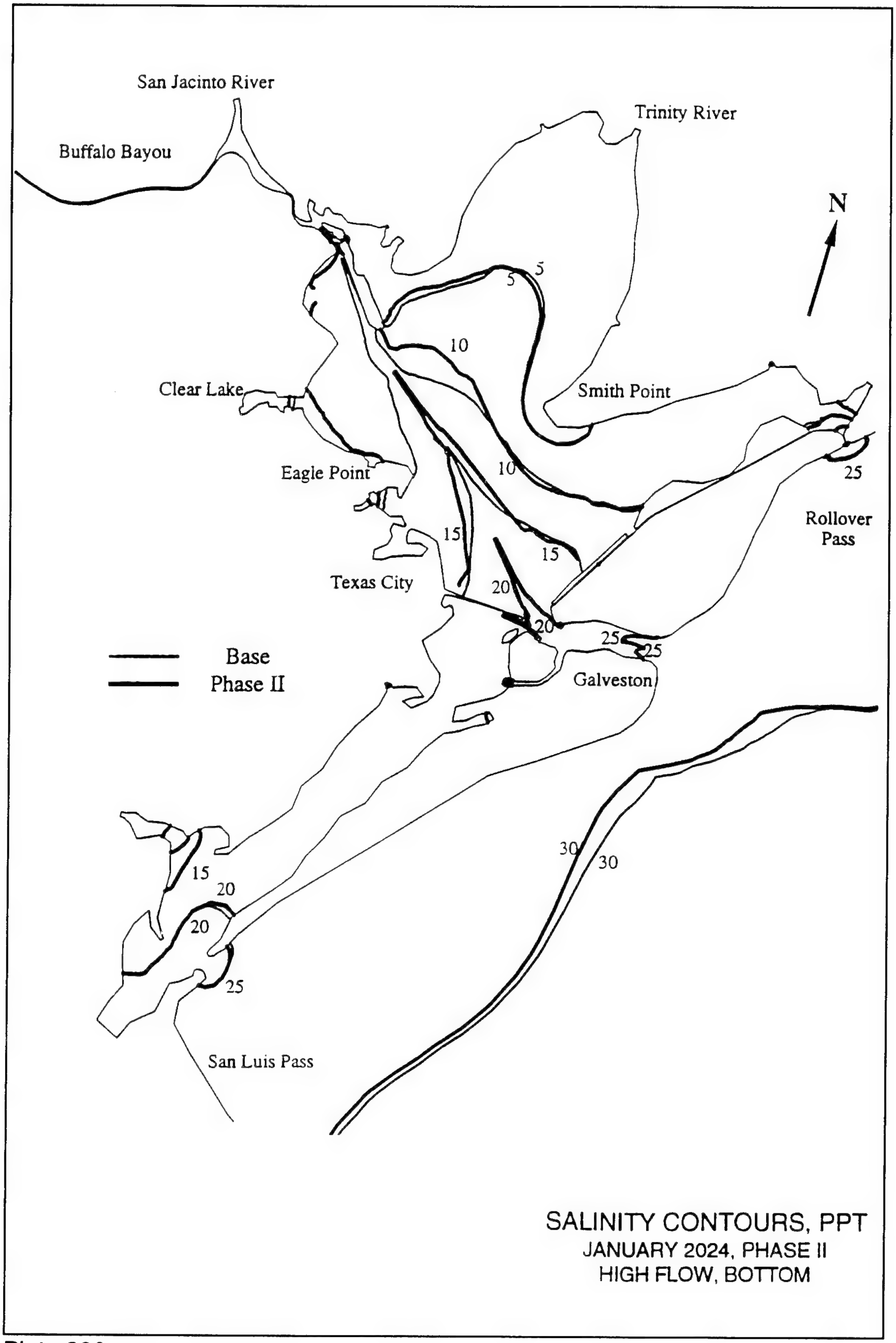
SALINITY CONTOURS, PPT
AUGUST 2024, PHASE II
MEDIUM FLOW, BOTTOM



SALINITY CONTOURS, PPT
SEPTEMBER 2024, PHASE II
MEDIUM FLOW , BOTTOM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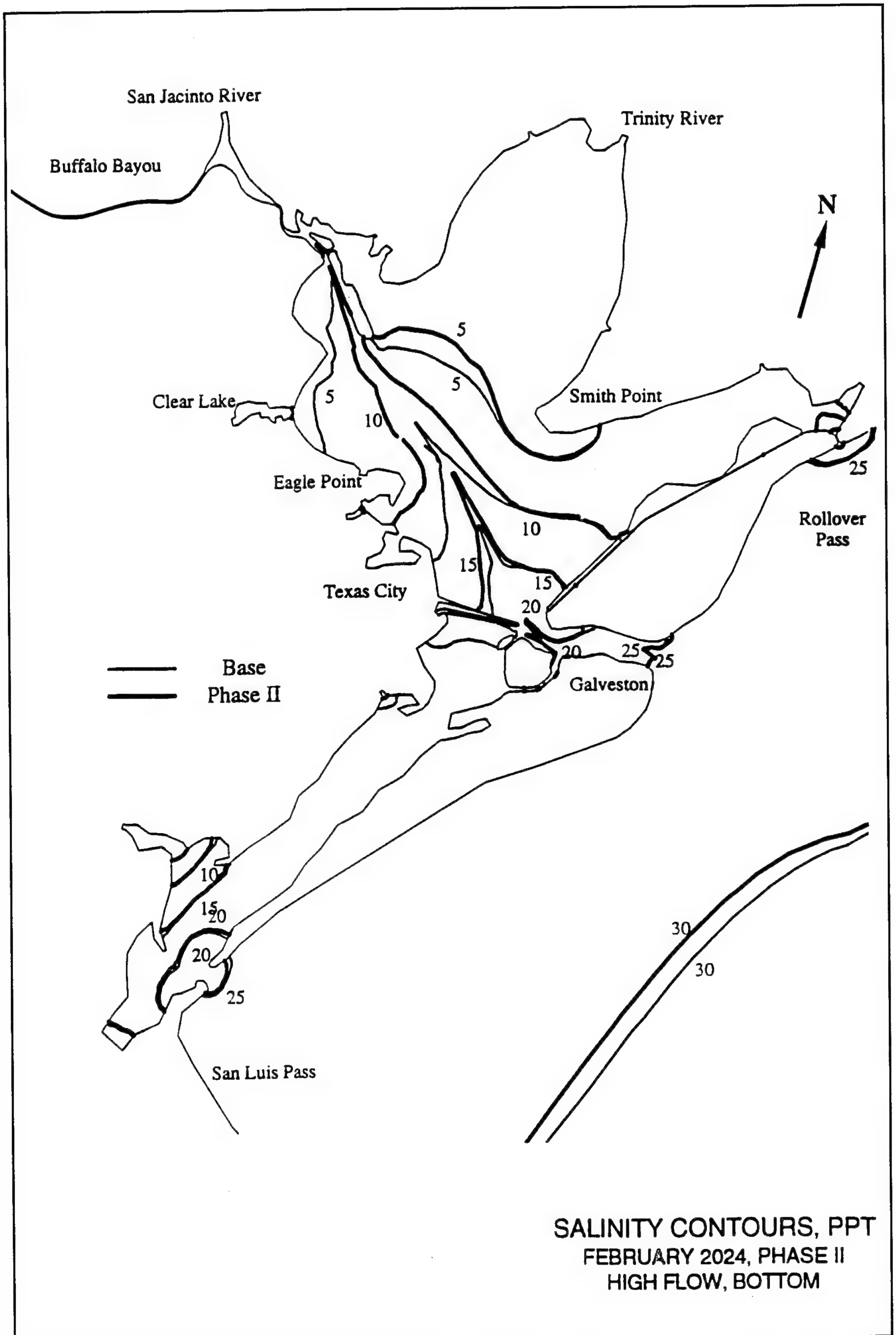
SALINITY CONTOURS, PPT
JANUARY 2024, PHASE II
HIGH FLOW, BOTTOM

Plate 390


San Jacinto River
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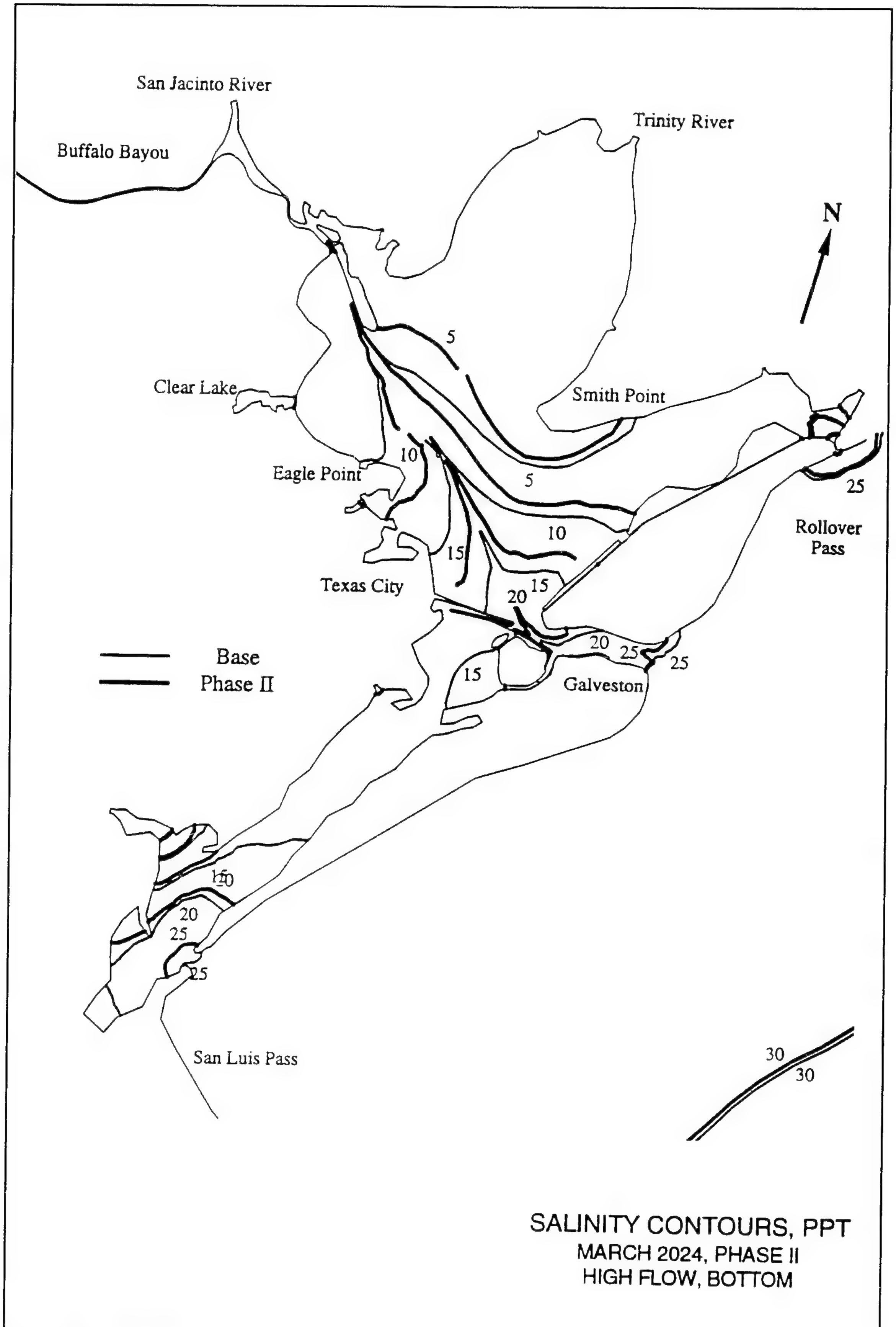
SALINITY CONTOURS, PPT
FEBRUARY 2024, PHASE II
HIGH FLOW, BOTTOM


San Jacinto River
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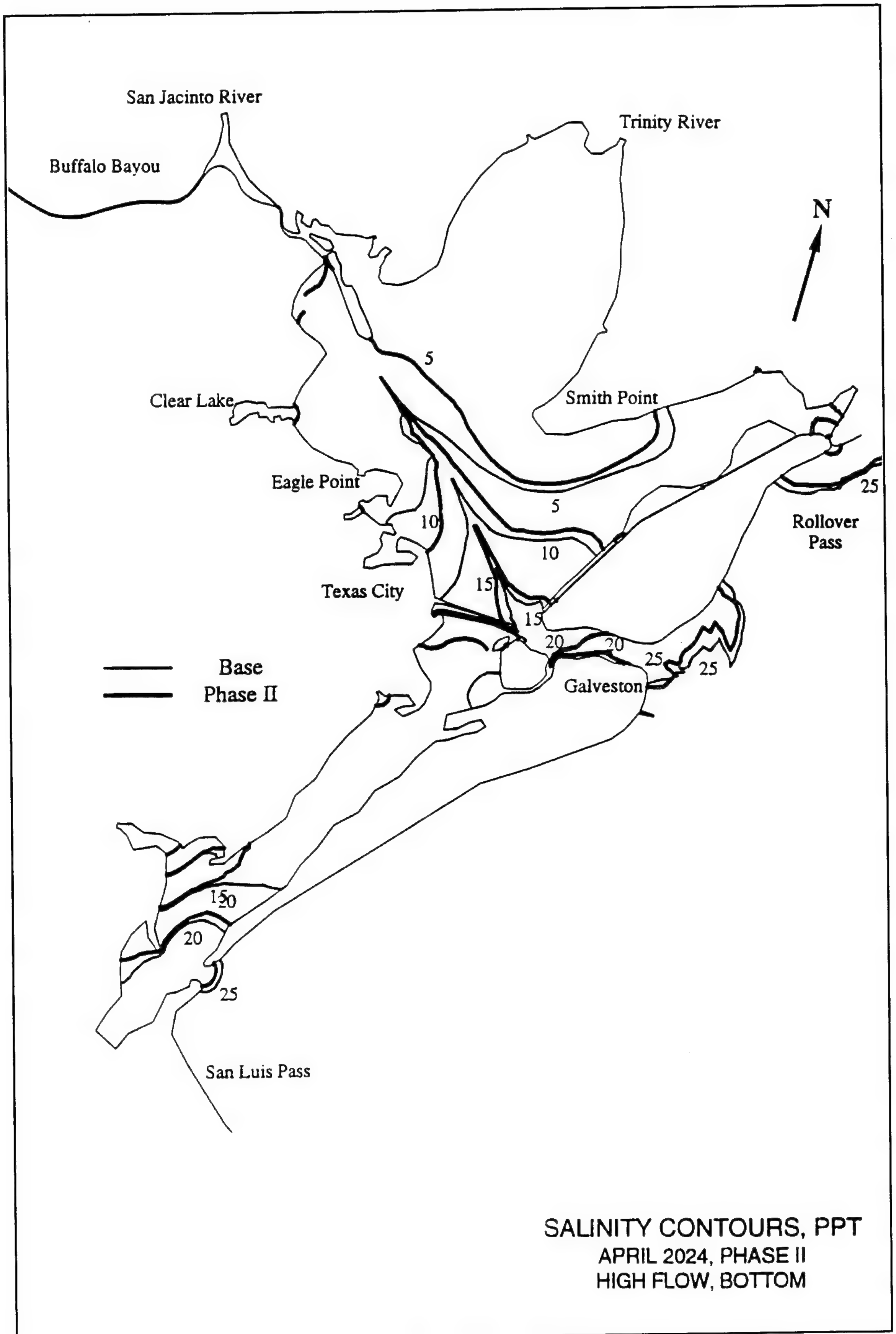
SALINITY CONTOURS, PPT
MARCH 2024, PHASE II
HIGH FLOW, BOTTOM



San Jacinto River
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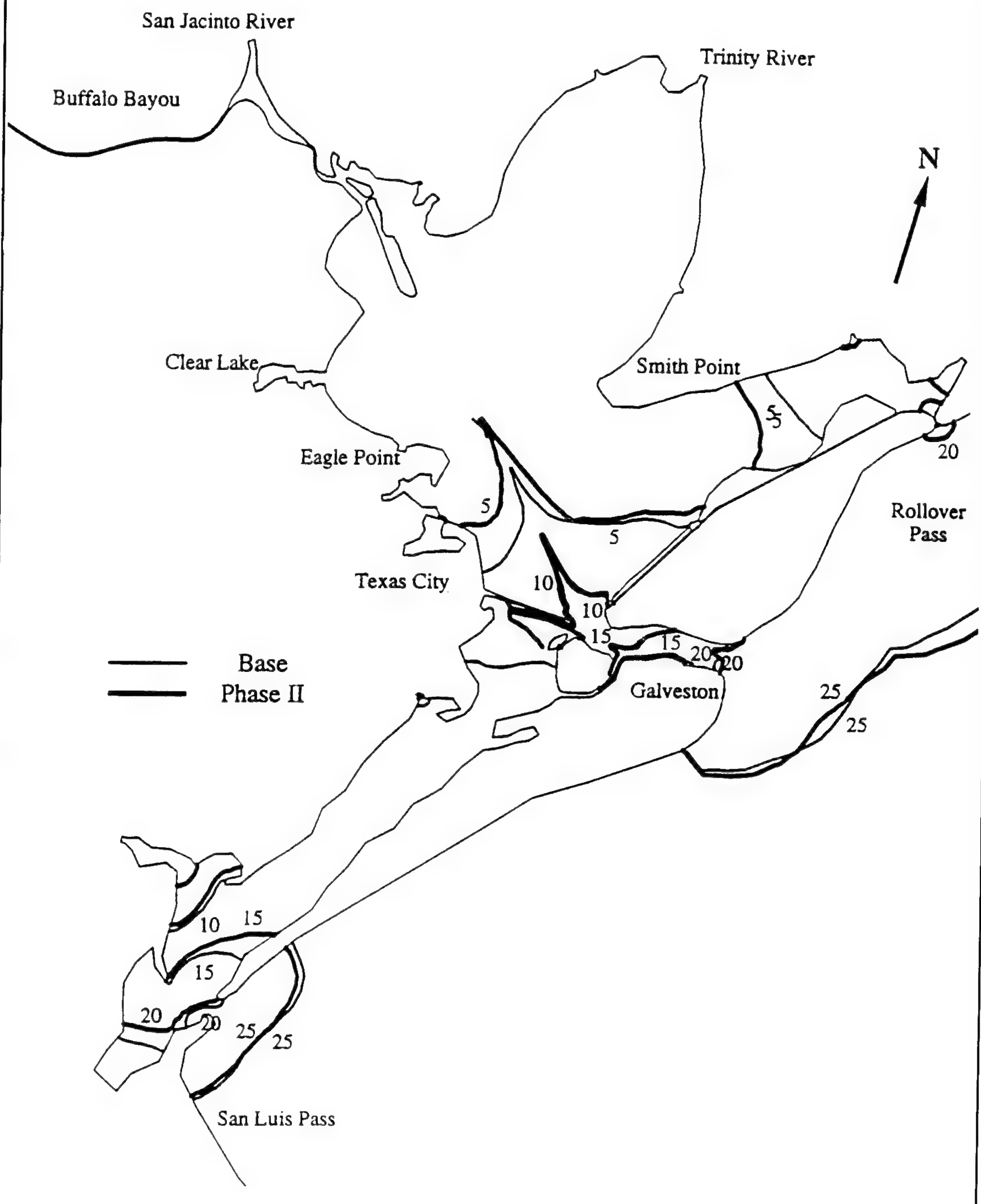
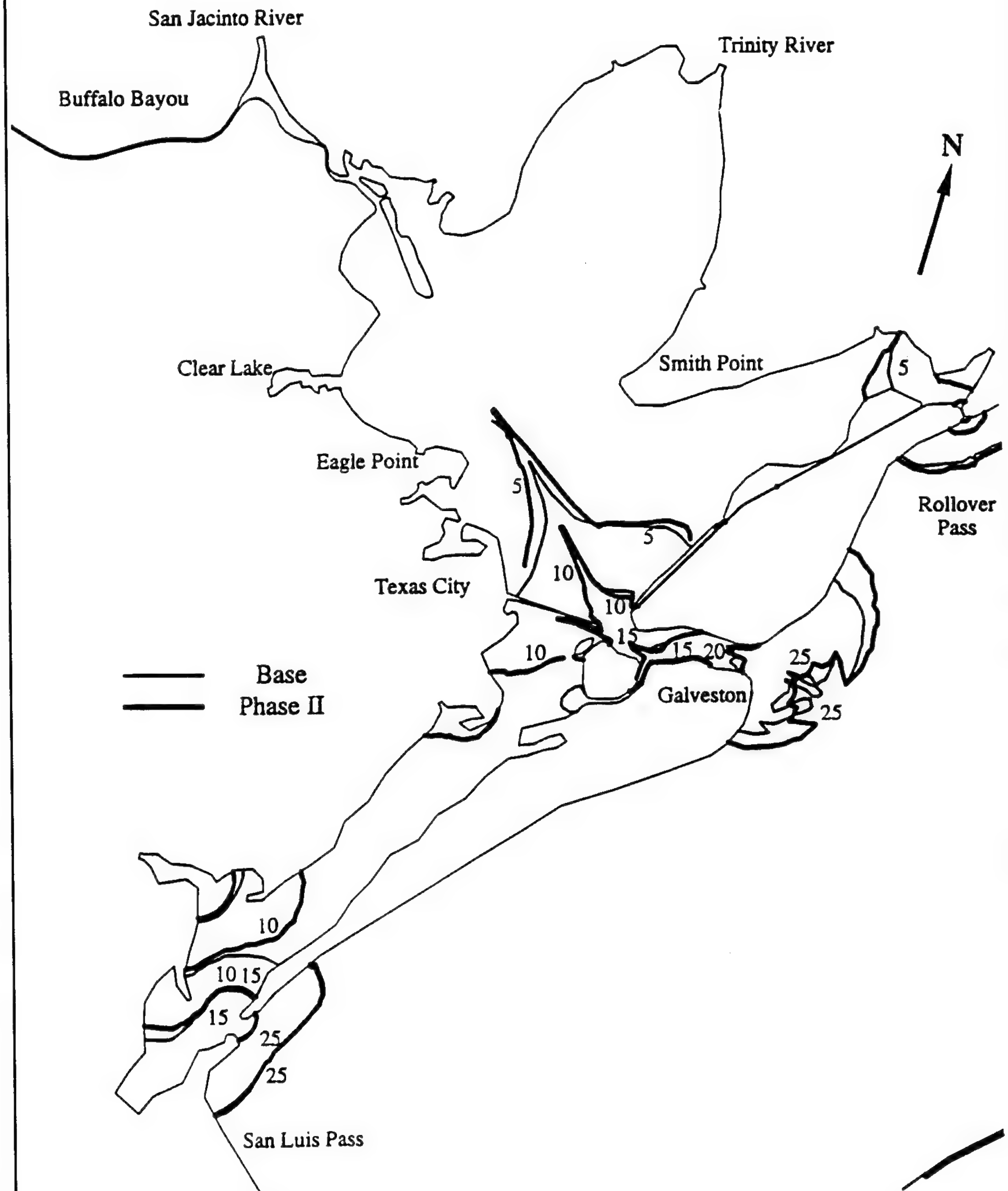
SALINITY CONTOURS, PPT
APRIL 2024, PHASE II
HIGH FLOW, BOTTOM



SALINITY CONTOURS, PPT
MAY 2024, PHASE II
HIGH FLOW, BOTTOM



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JUNE 2024, PHASE II
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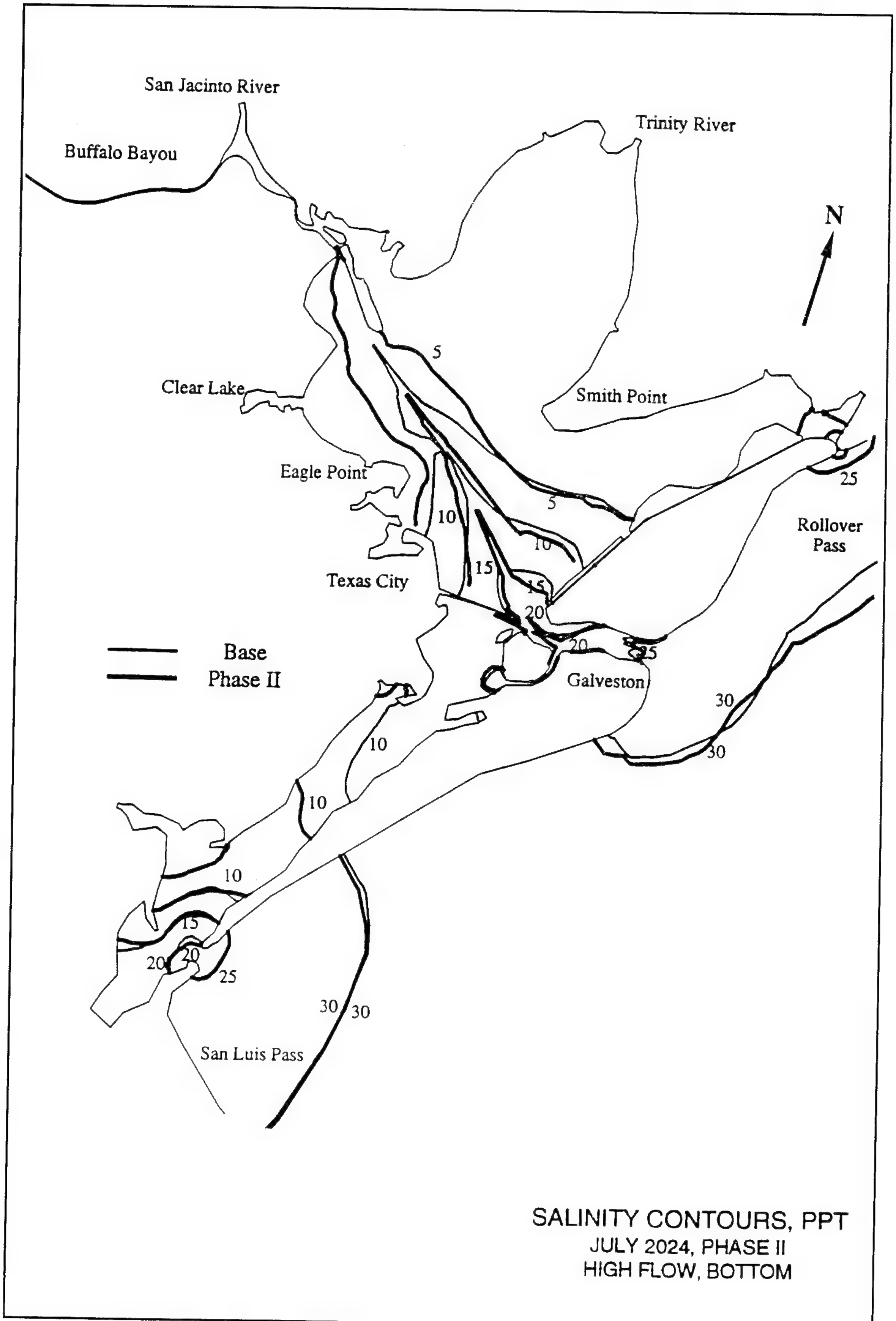
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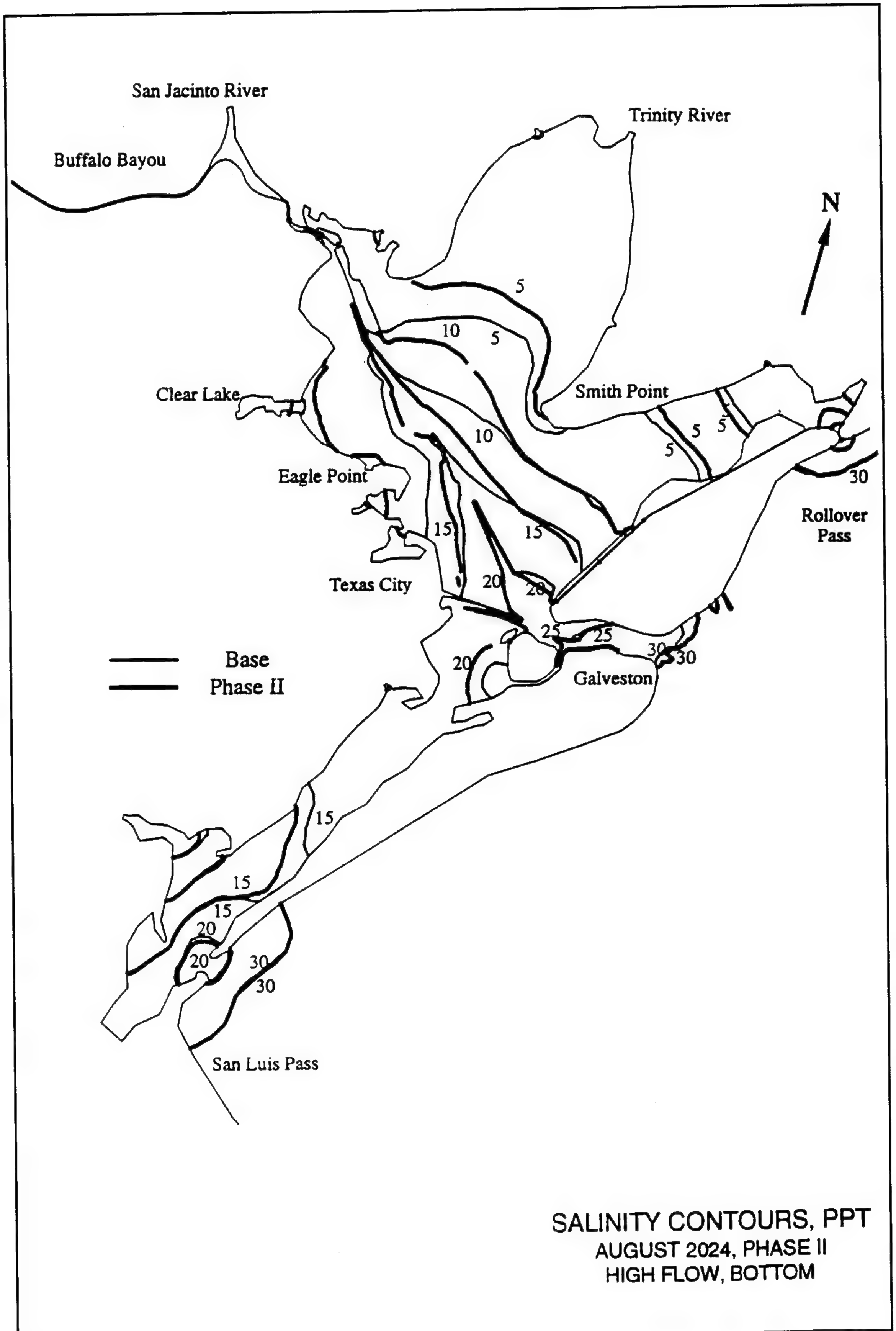
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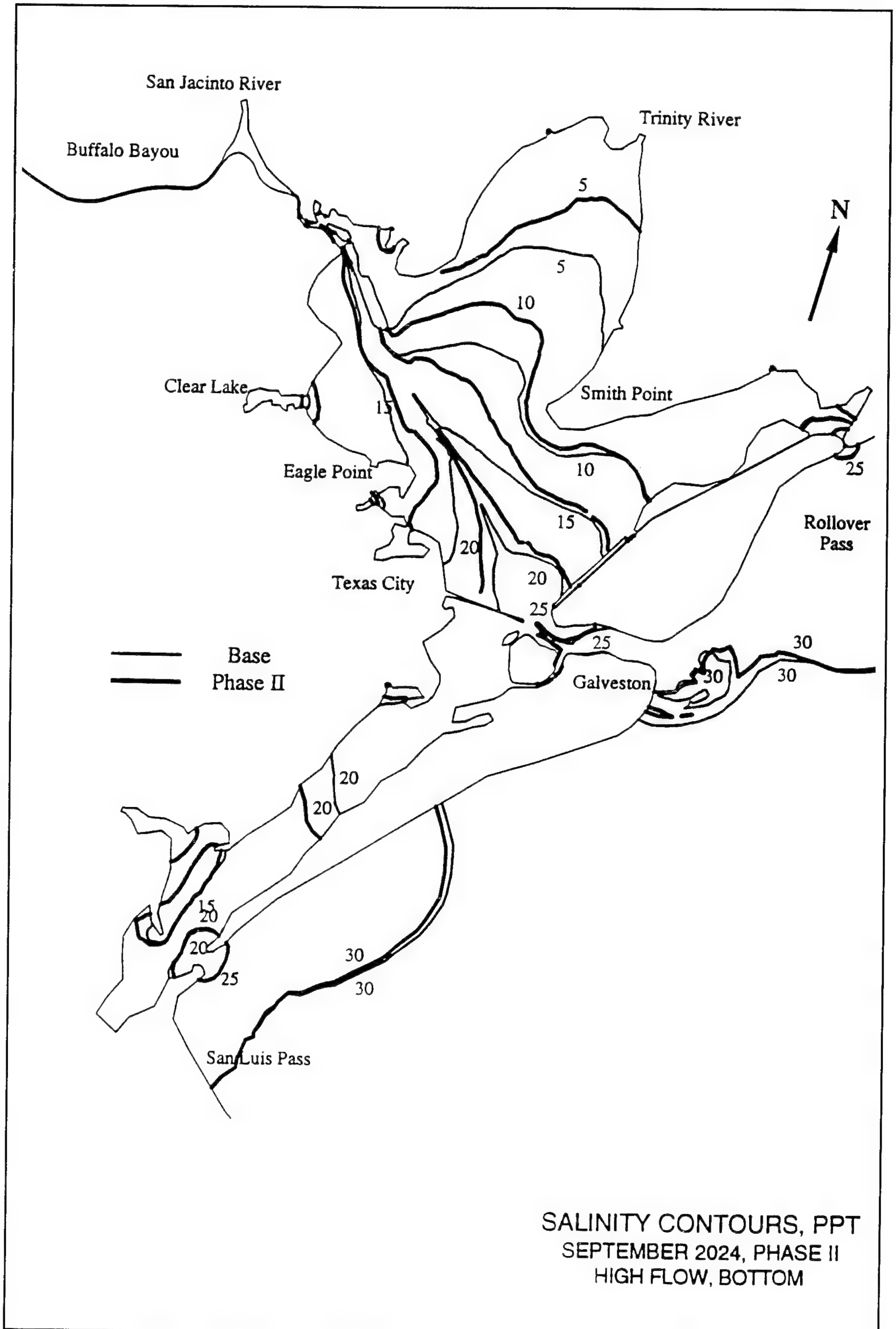

SALINITY CONTOURS, PPT
SEPTEMBER 2024, PHASE II
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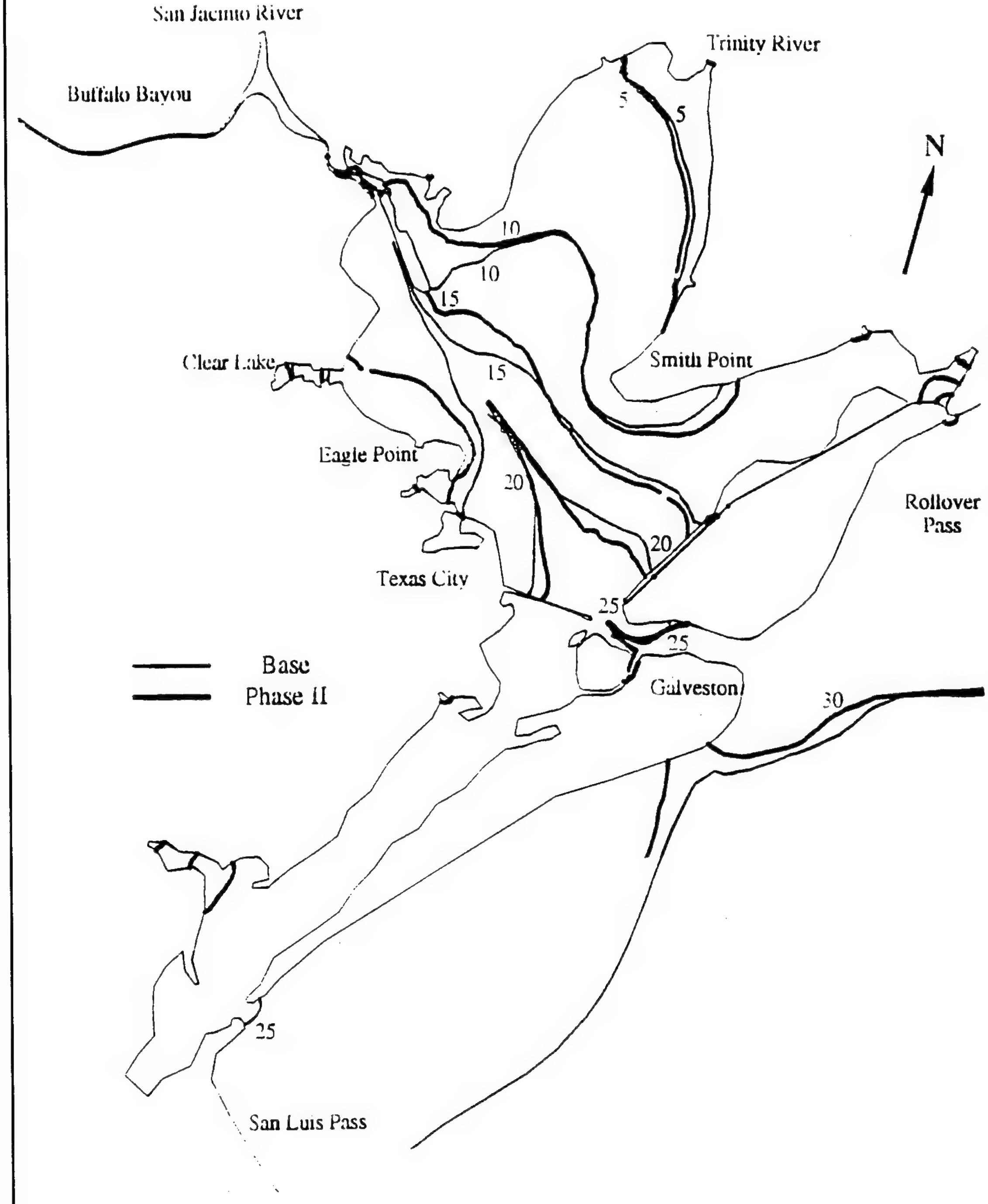
Plate 398



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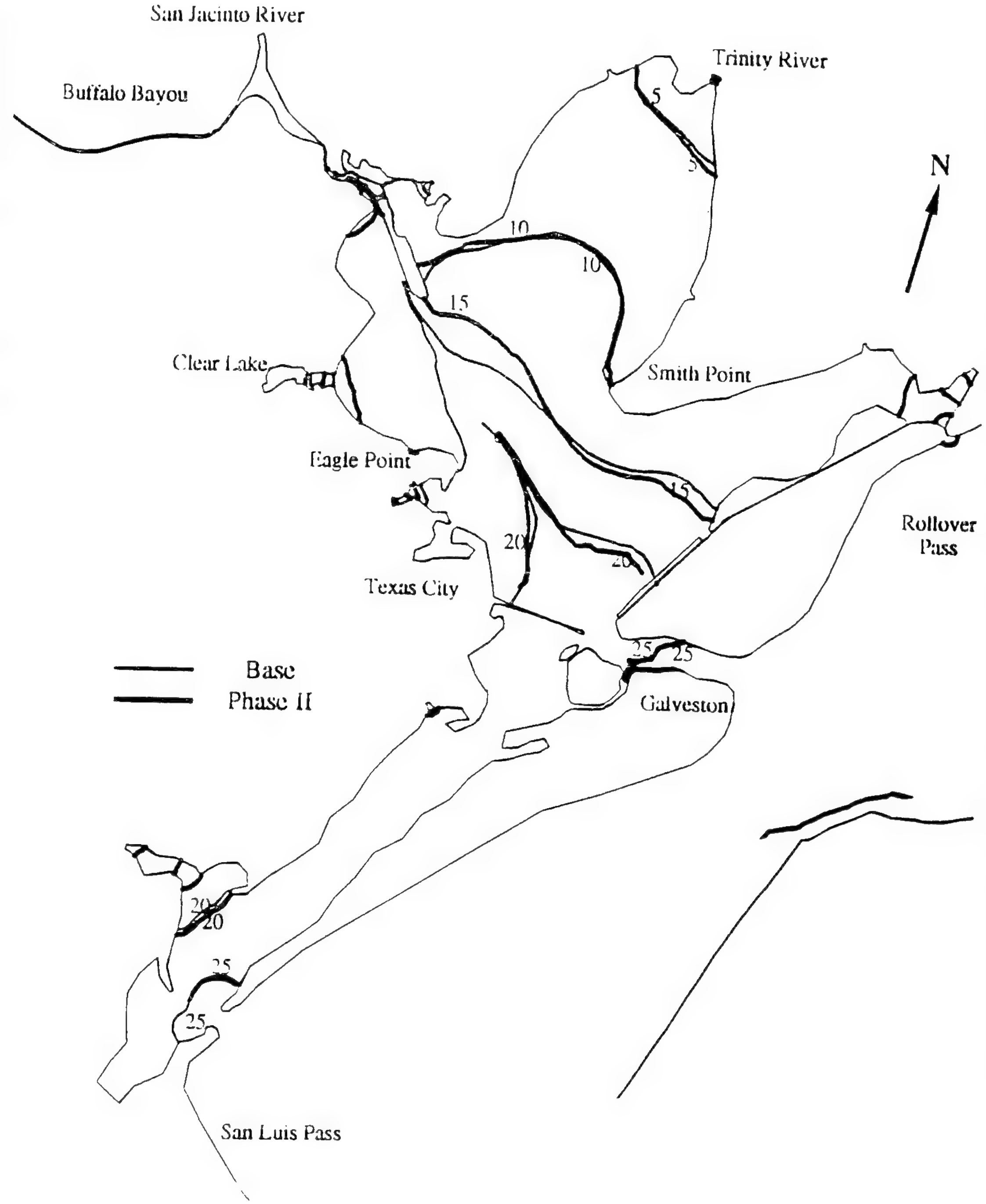

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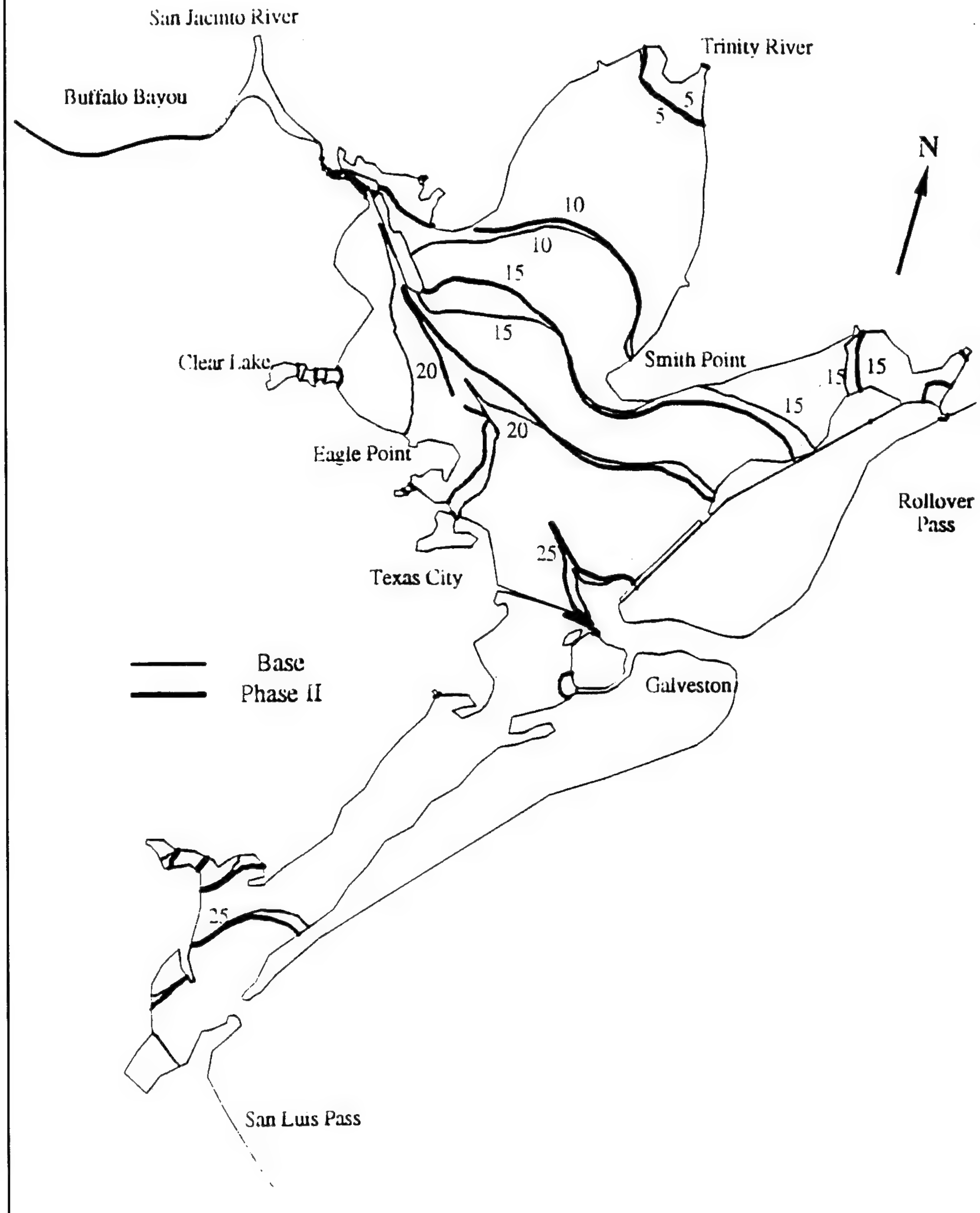

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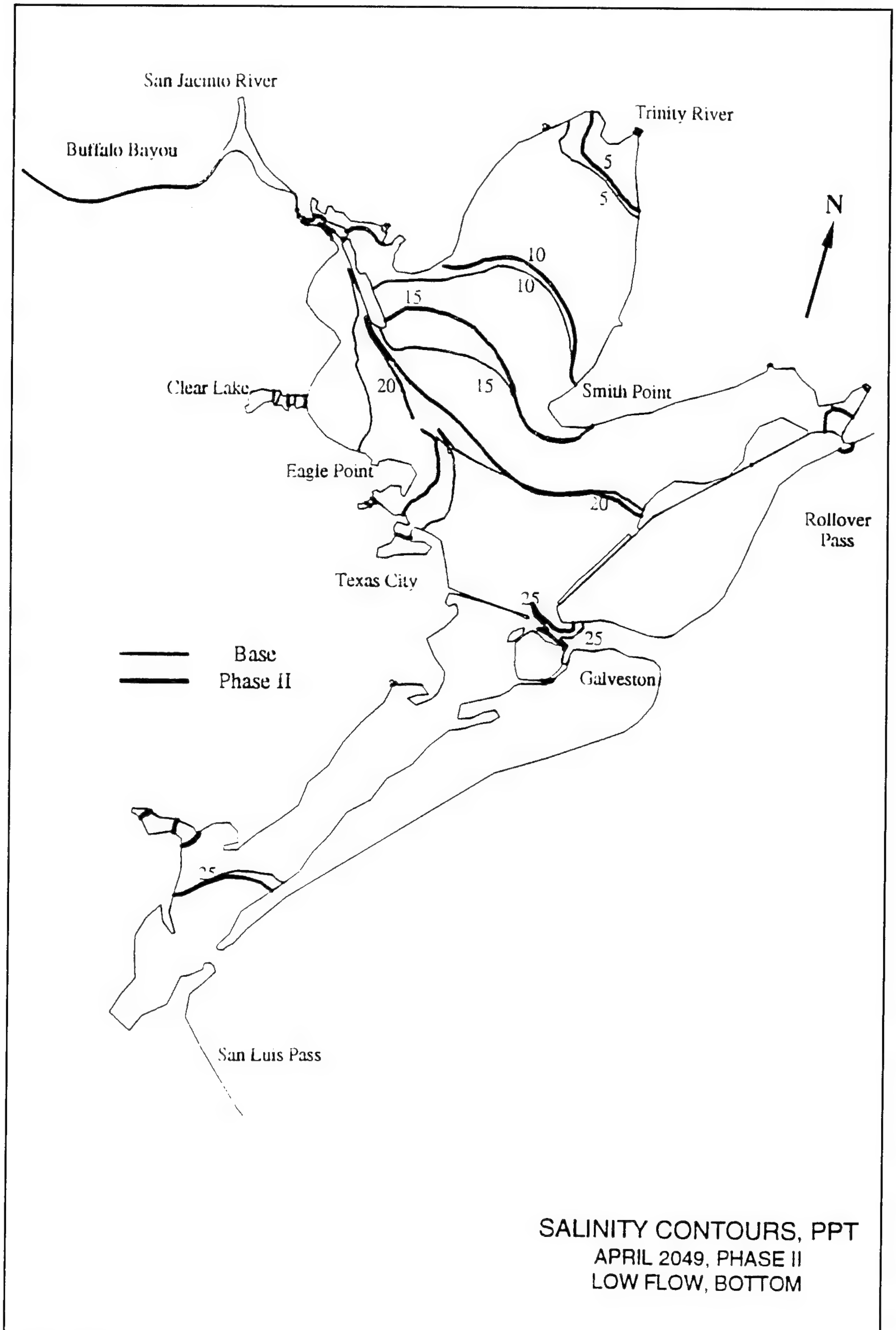
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APRIL 2049, PHASE II
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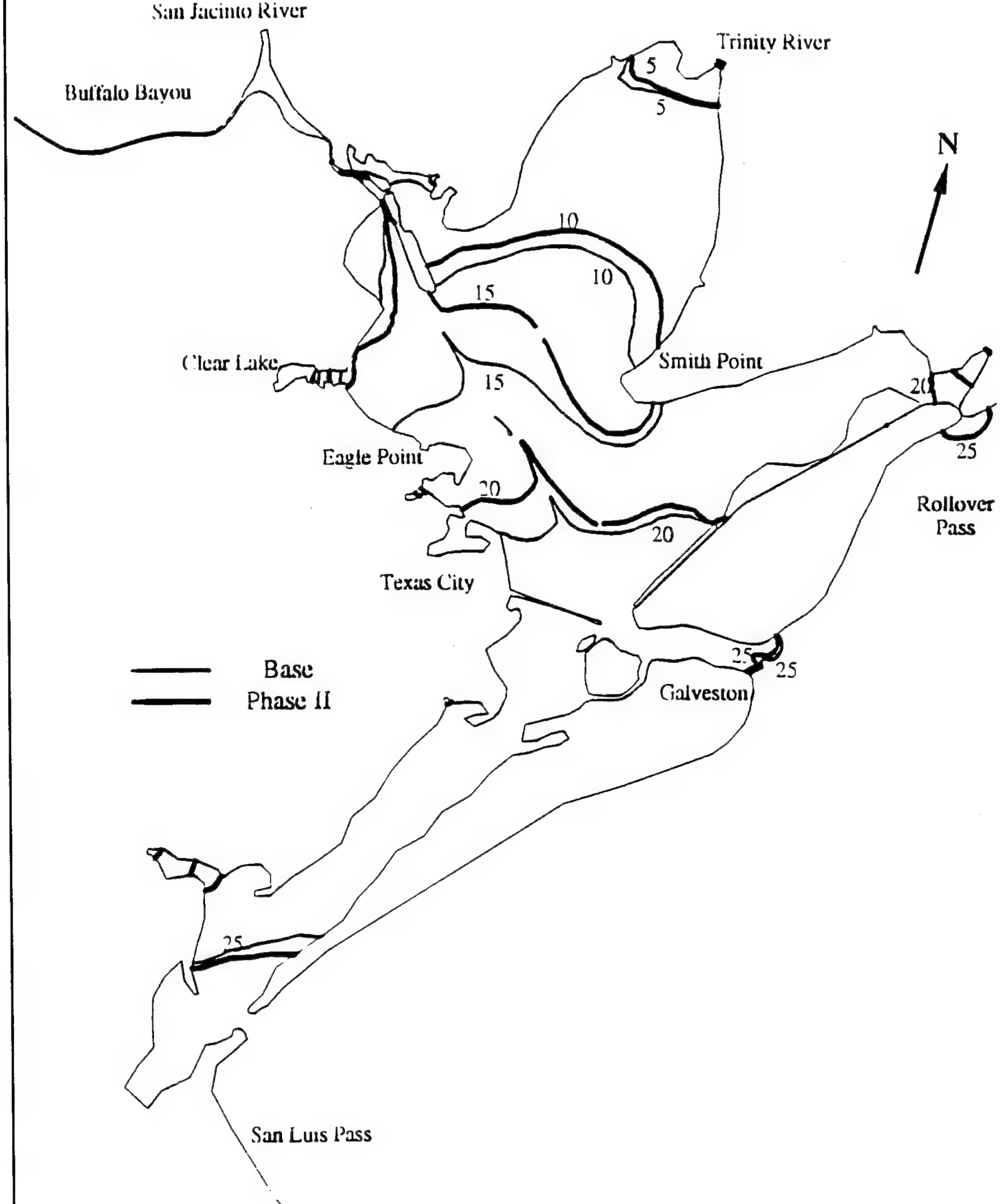

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MAY 2049, PHASE II
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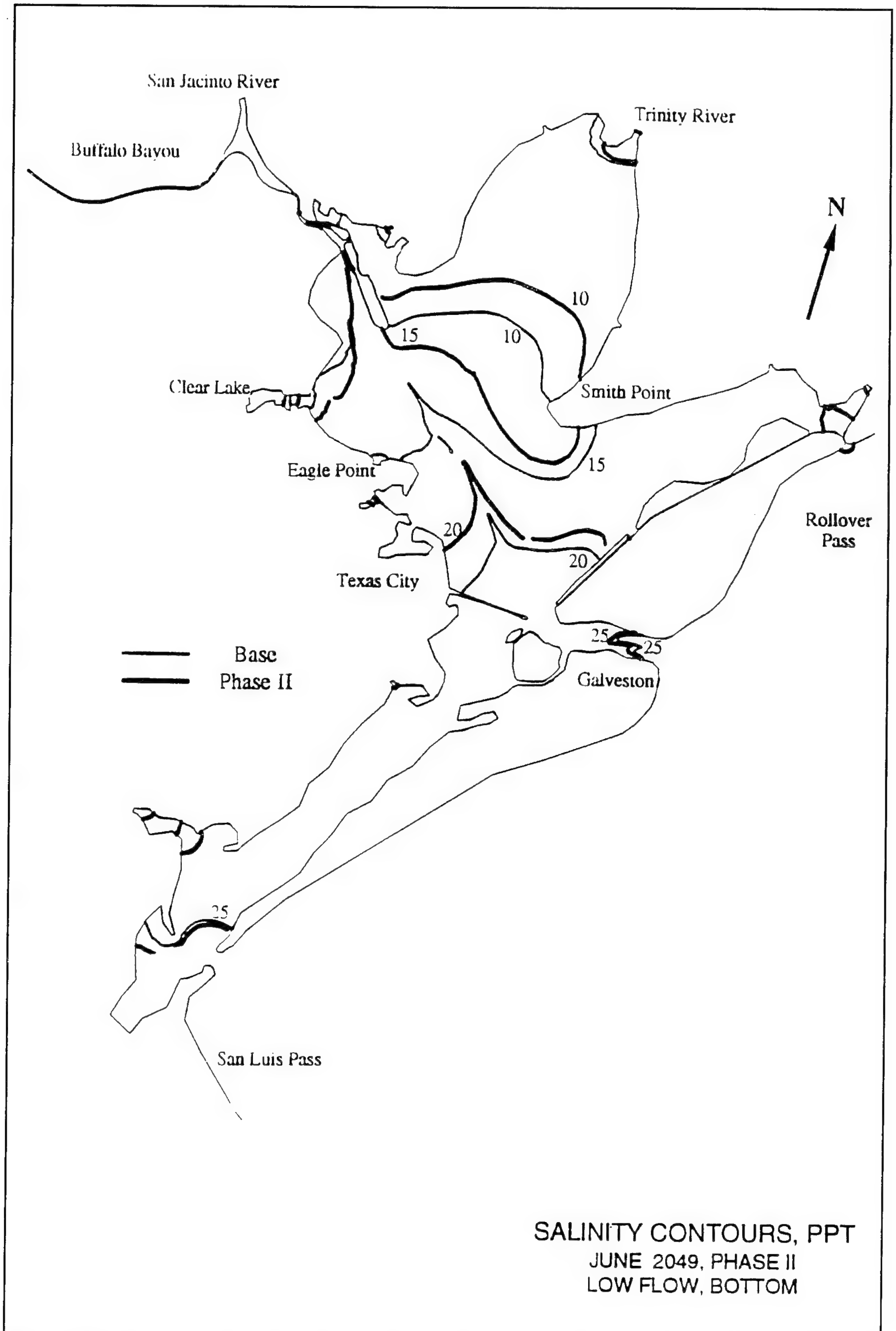
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JUNE 2049, PHASE II
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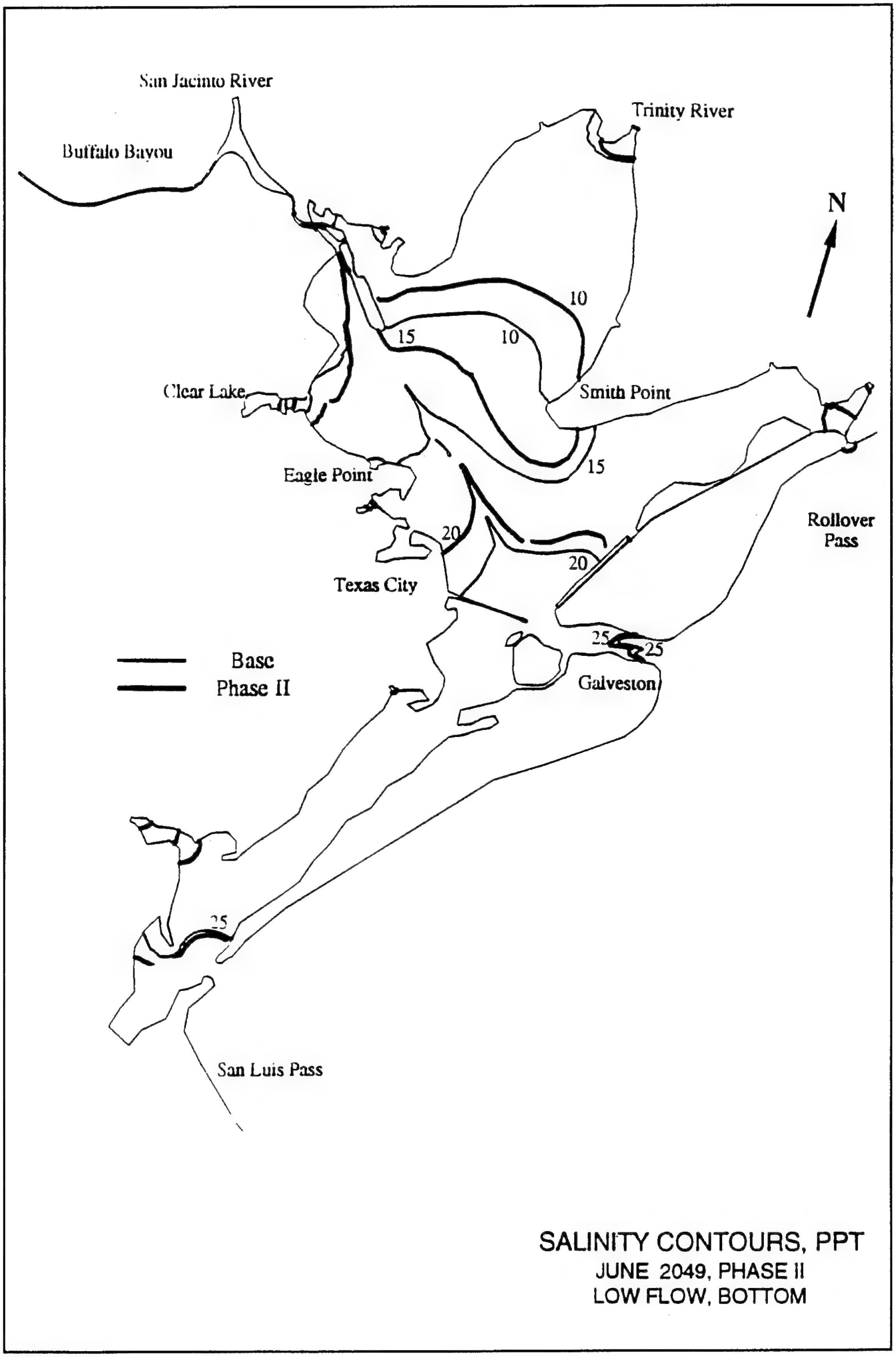
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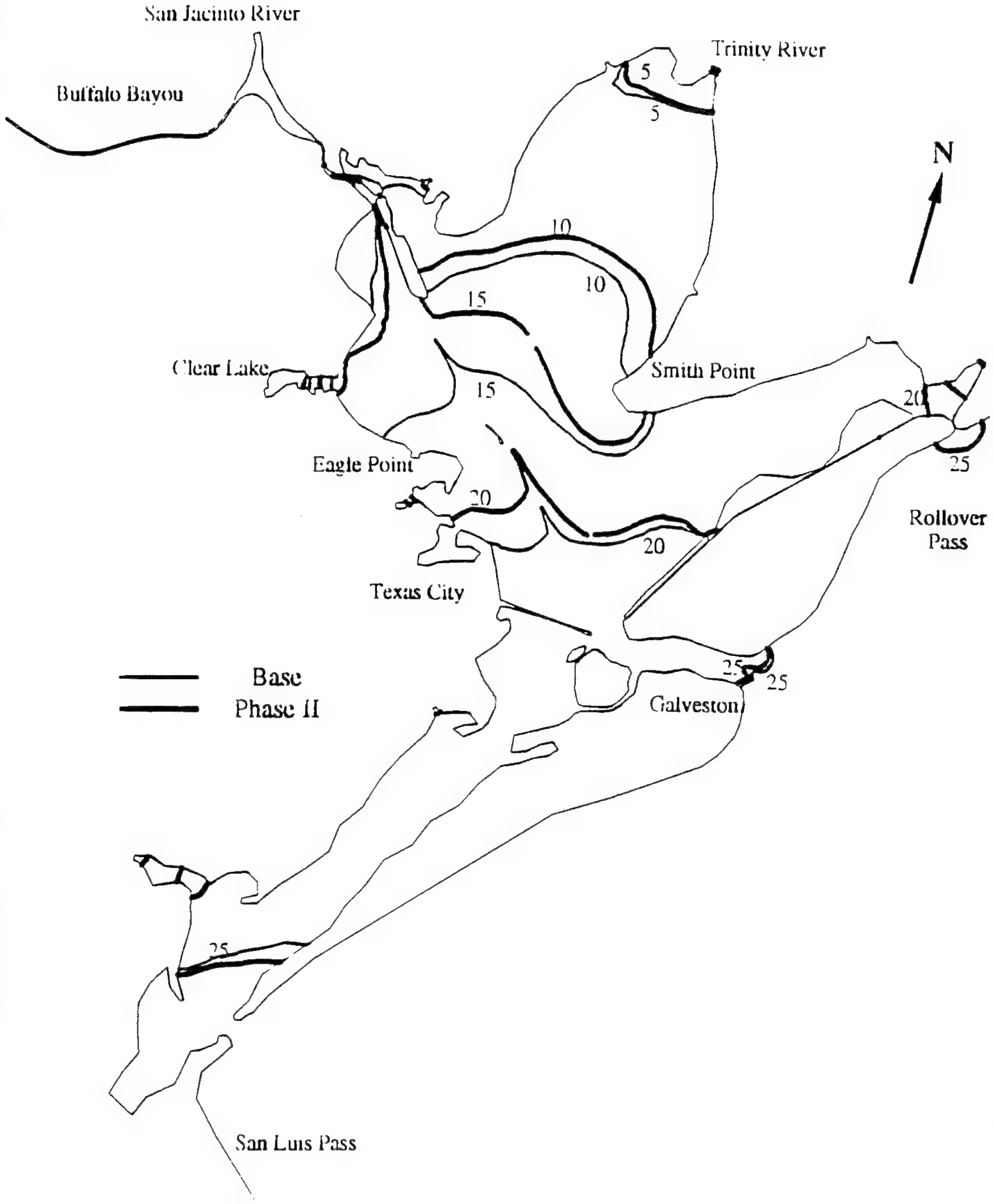
SALINITY CONTOURS, PPT
JUNE 2049, PHASE II
LOW FLOW, BOTTOM

Plate 404



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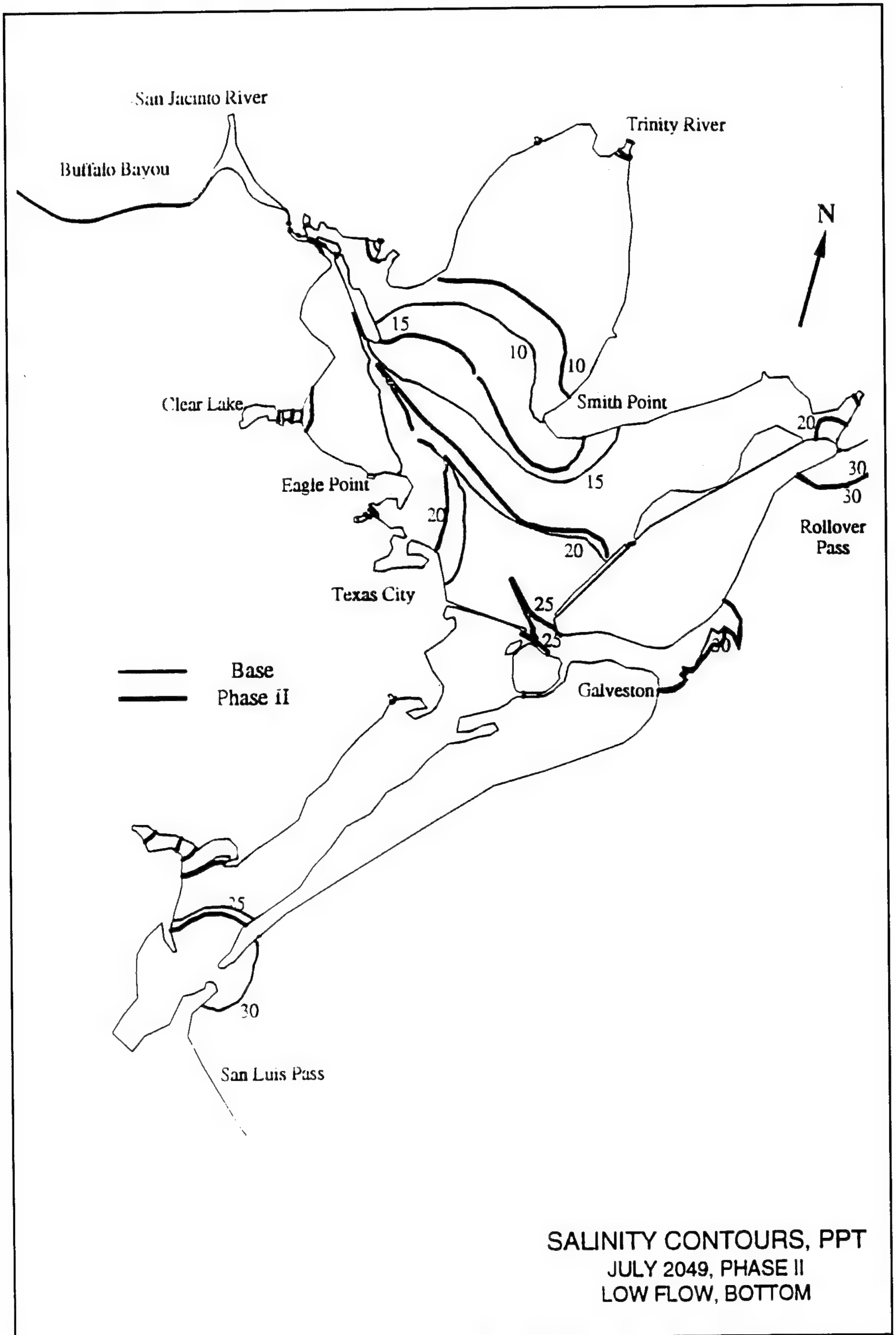
MAY 2049, PHASE II
LOW FLOW, BOTTOM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JULY 2049, PHASE II
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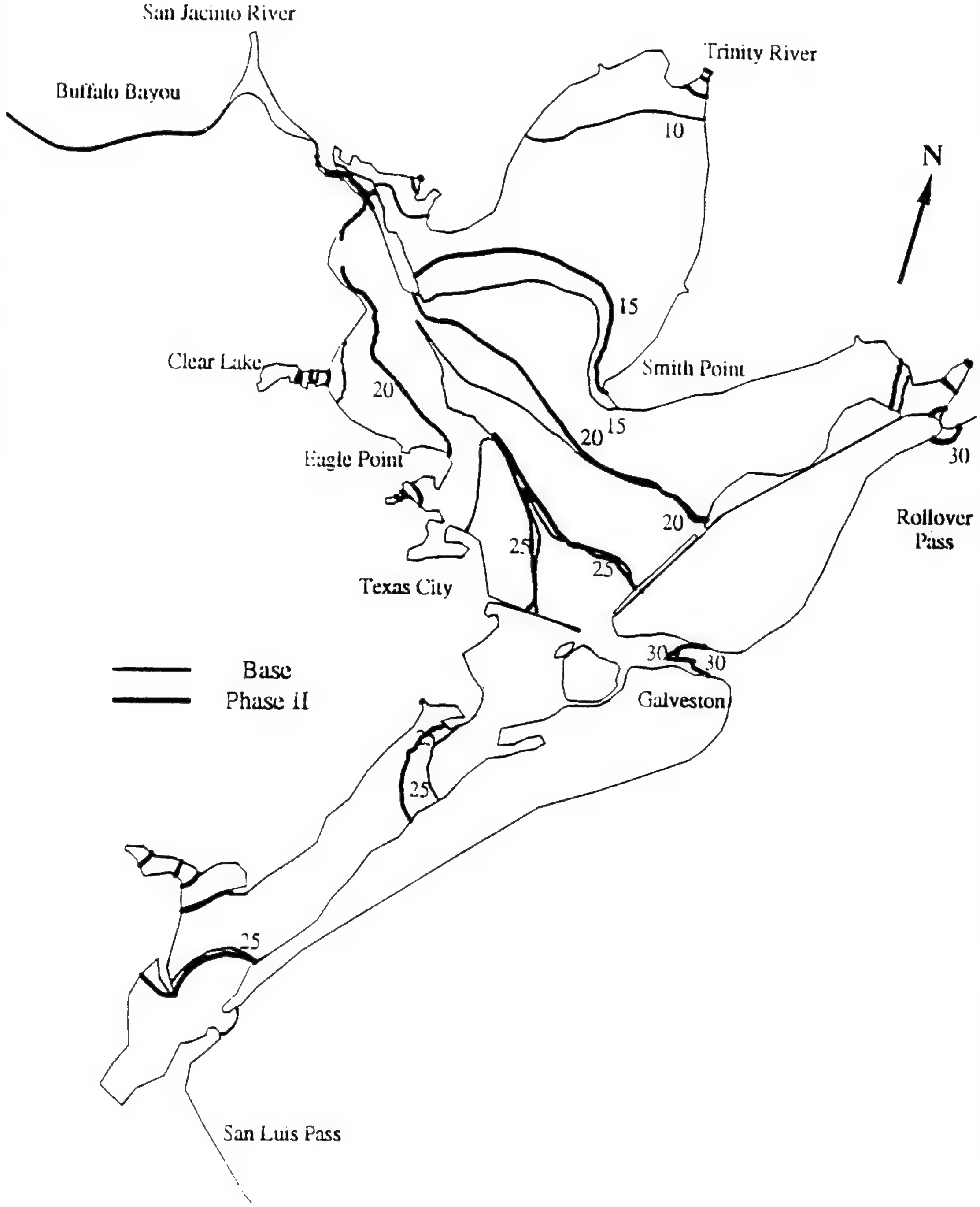

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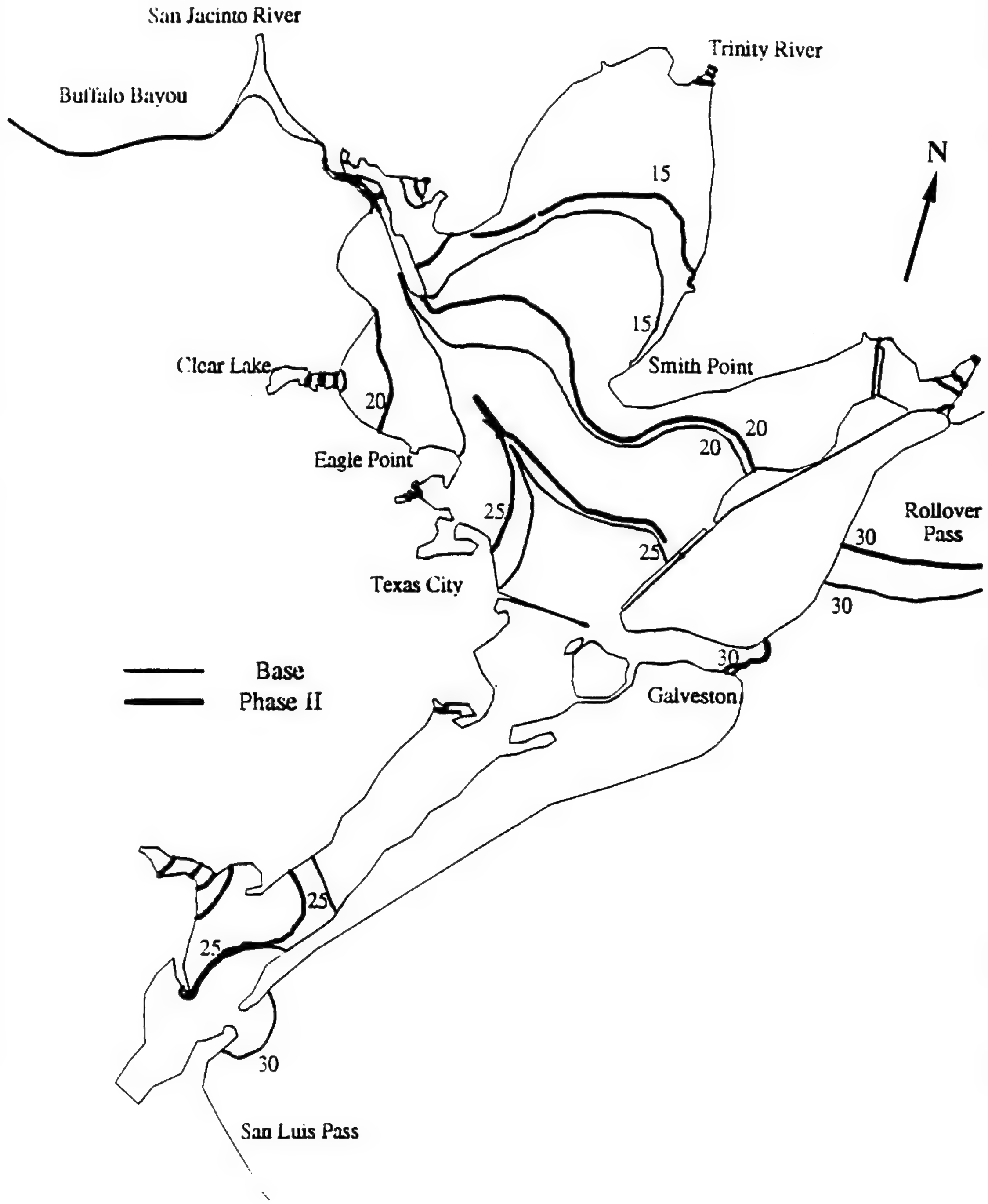
AUGUST 2049, PHASE II
LOW FLOW, BOTTOM



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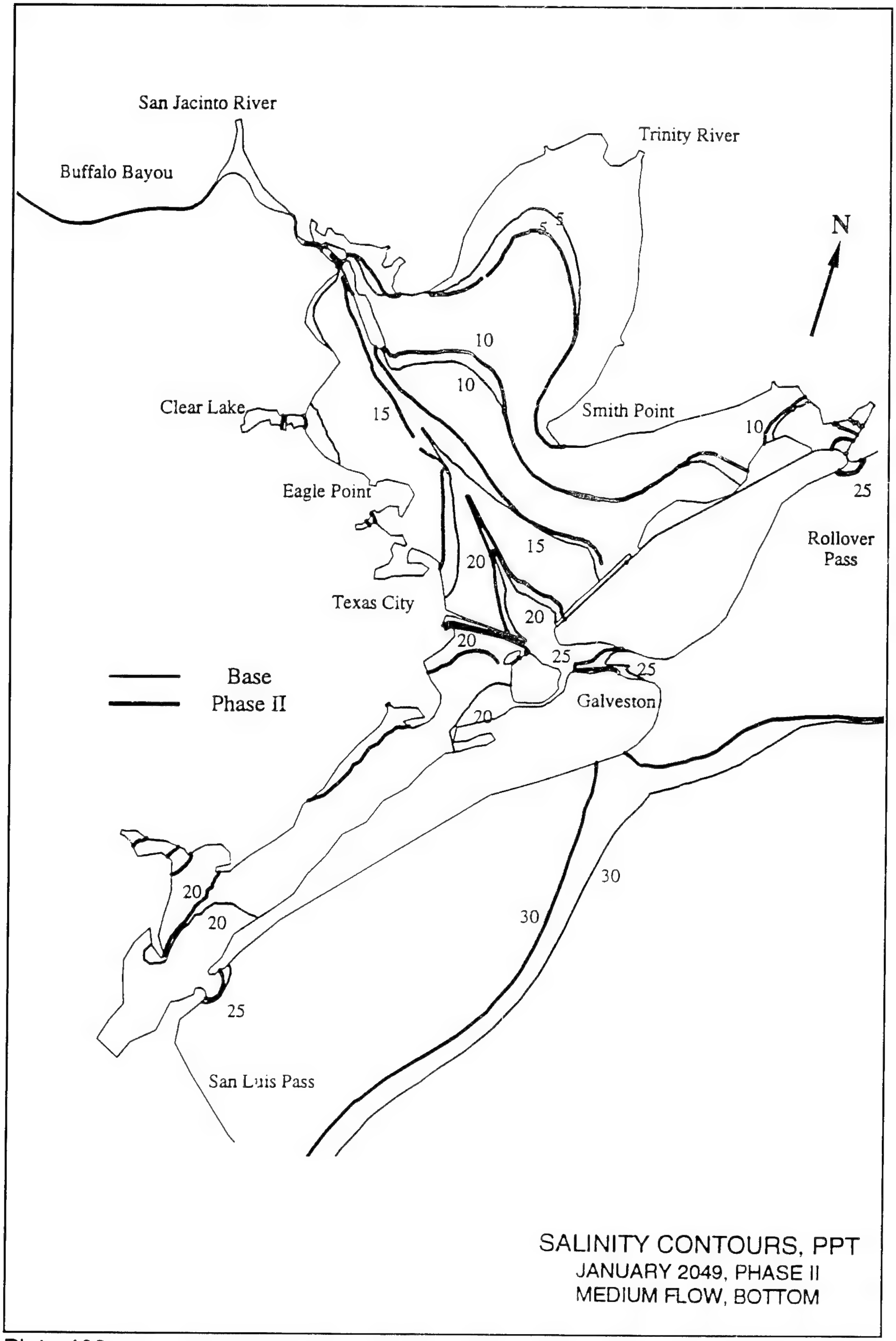
SEPTEMBER 2049, PHASE II
LOW FLOW, BOTTOM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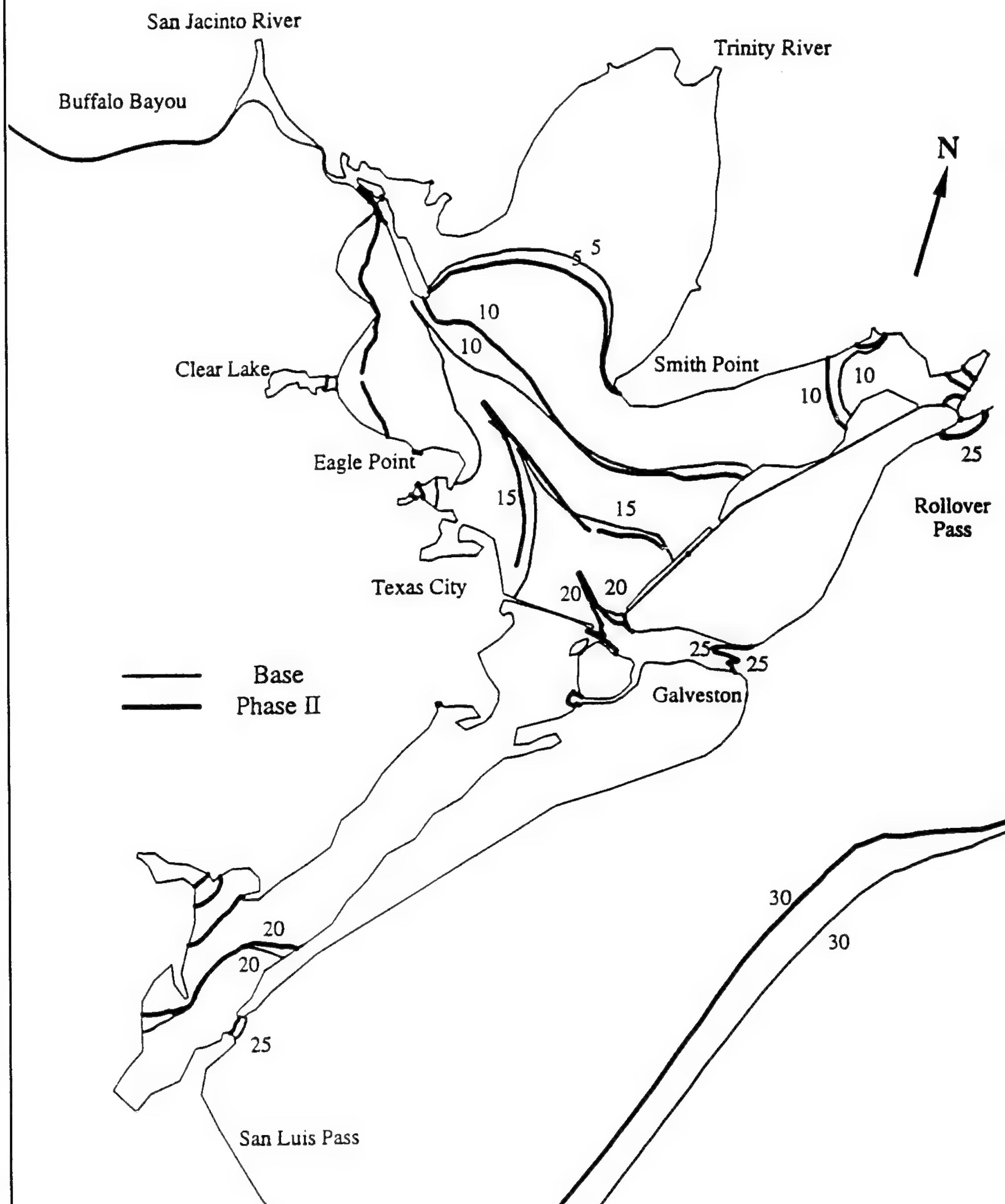
SALINITY CONTOURS, PPT
JANUARY 2049, PHASE II
MEDIUM FLOW, BOTTOM

Plate 408



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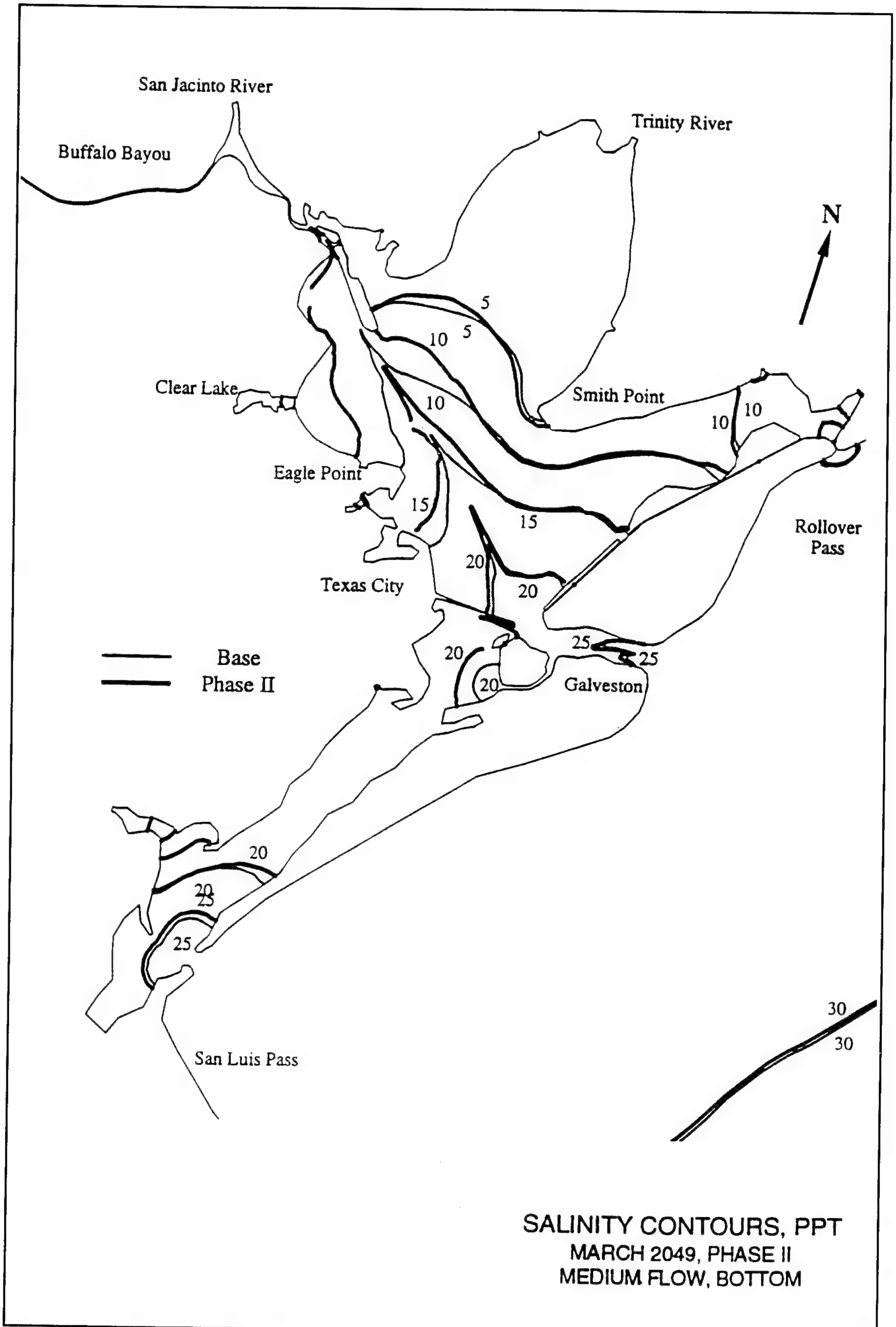
FEBRUARY 2049, PHASE II
MEDIUM FLOW, BOTTOM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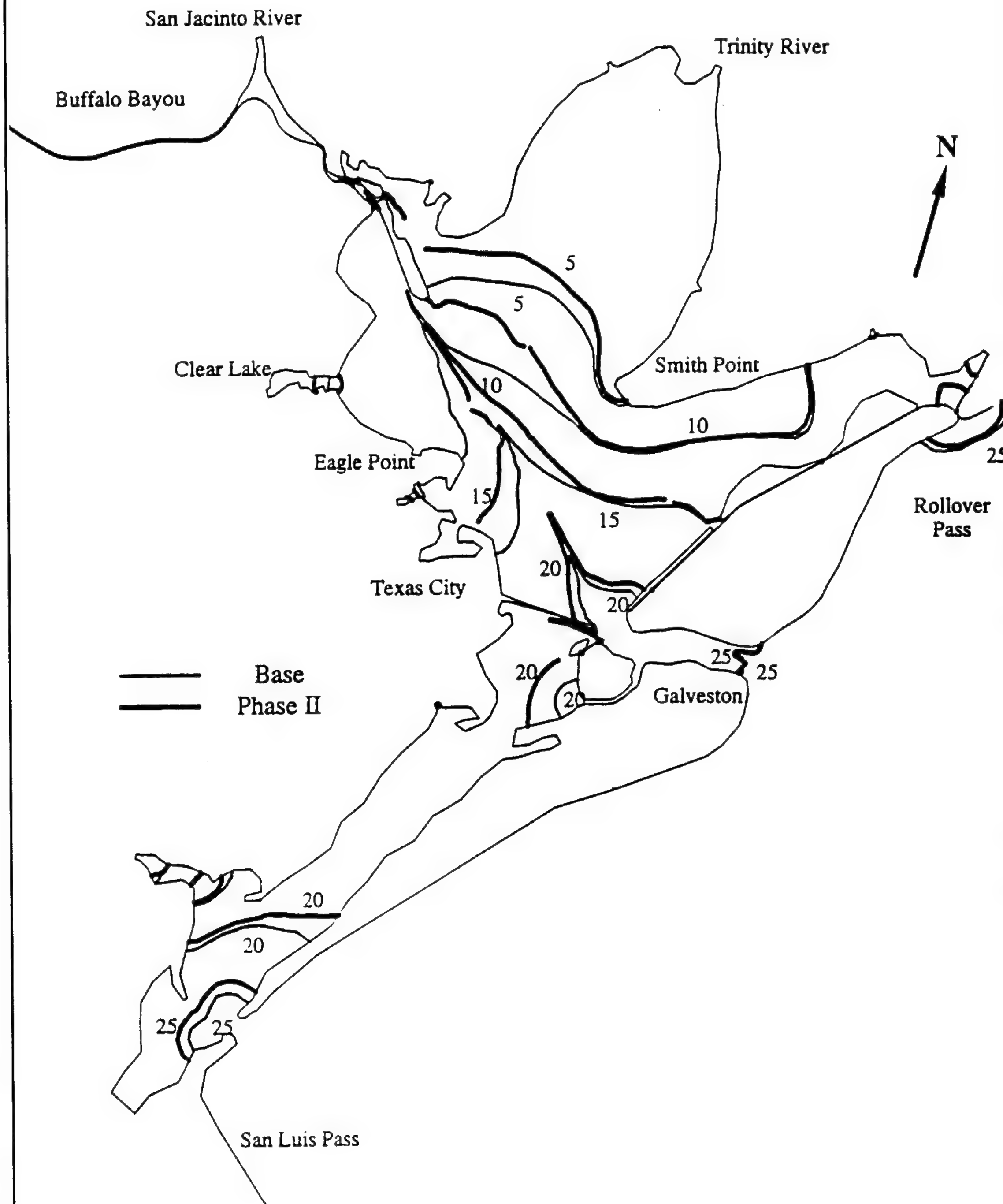
MARCH 2049, PHASE II
MEDIUM FLOW, BOTTOM



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APRIL 2049, PHASE II
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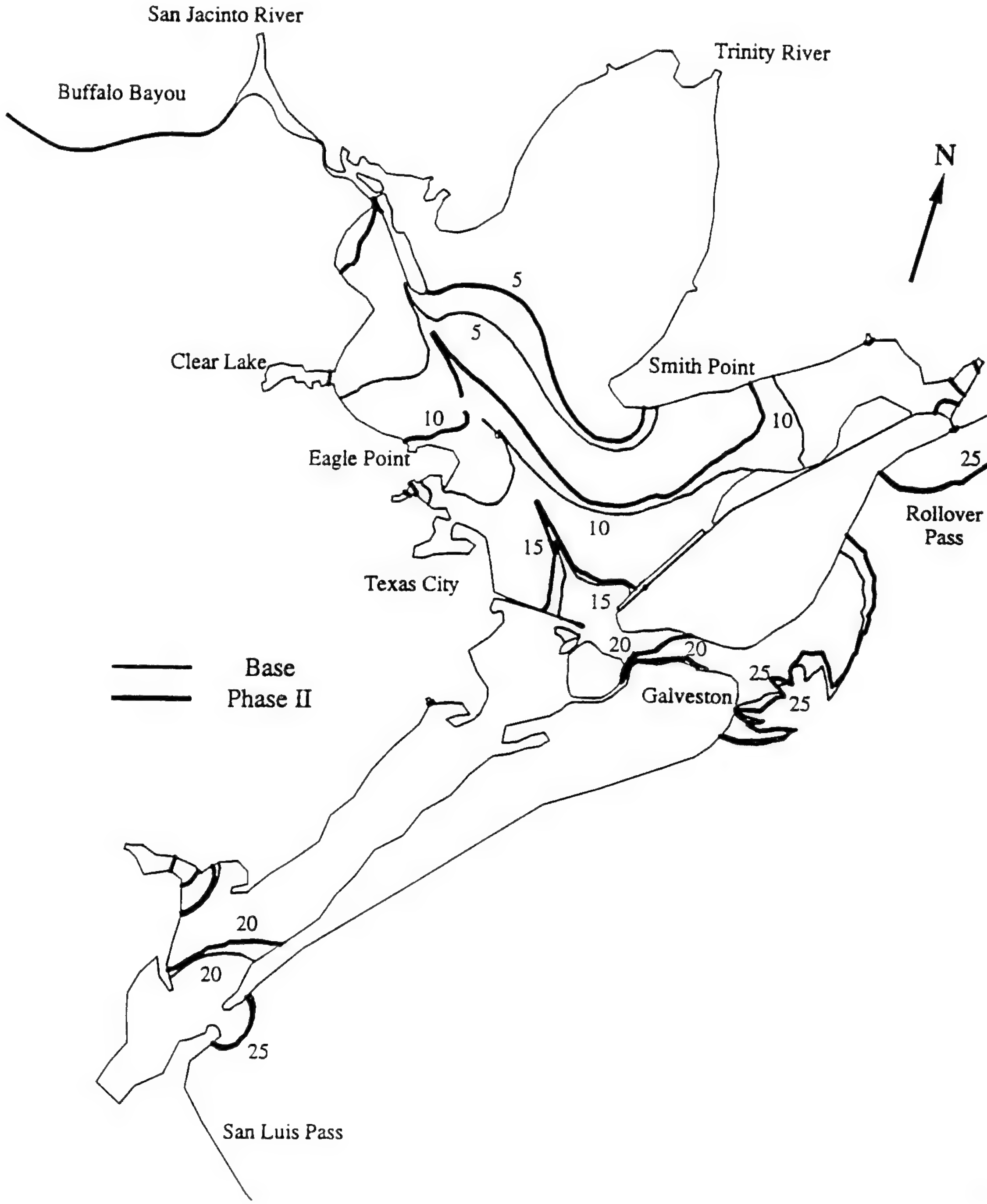

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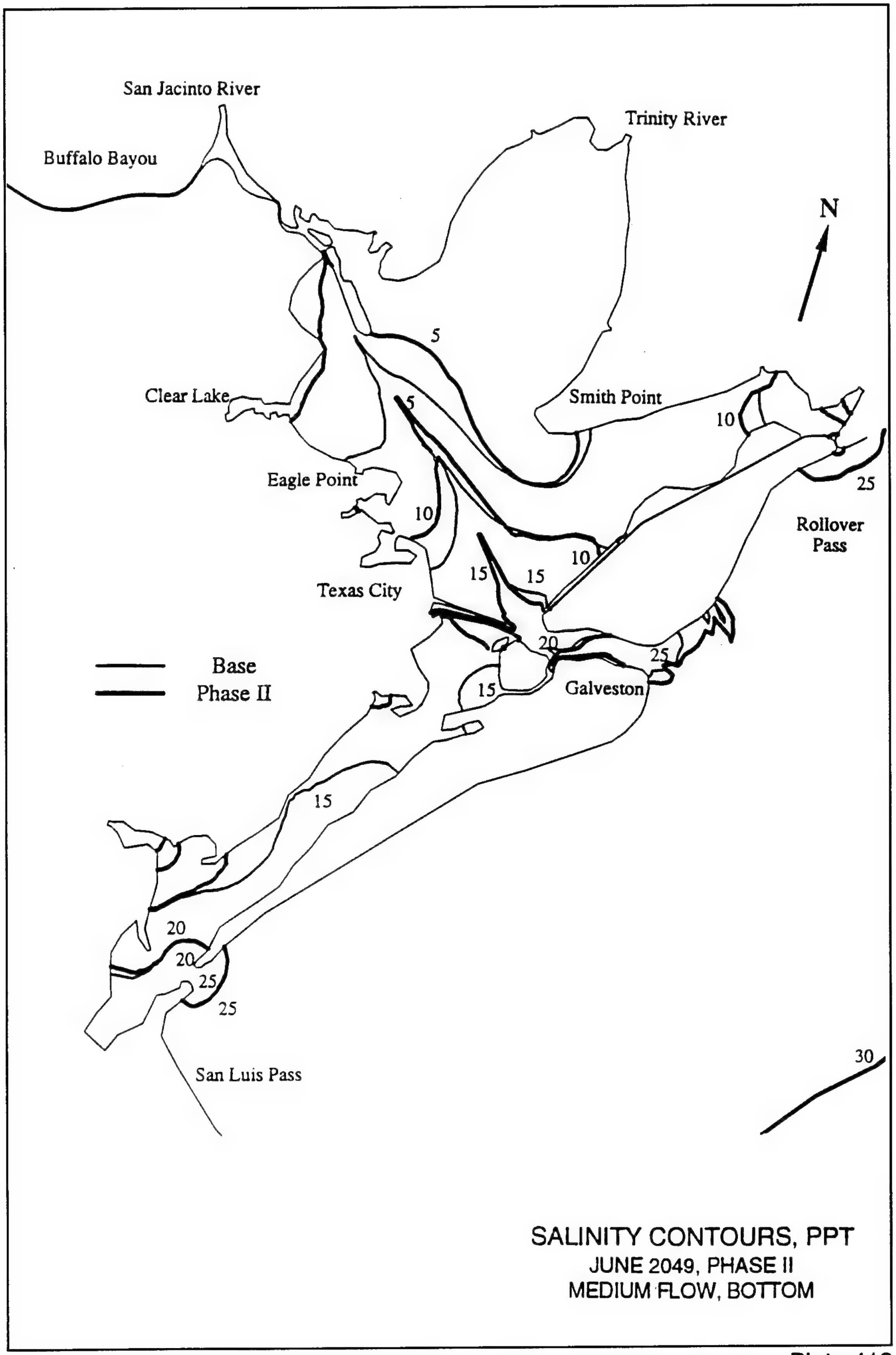
MAY 2049, PHASE II
MEDIUM FLOW, BOTTOM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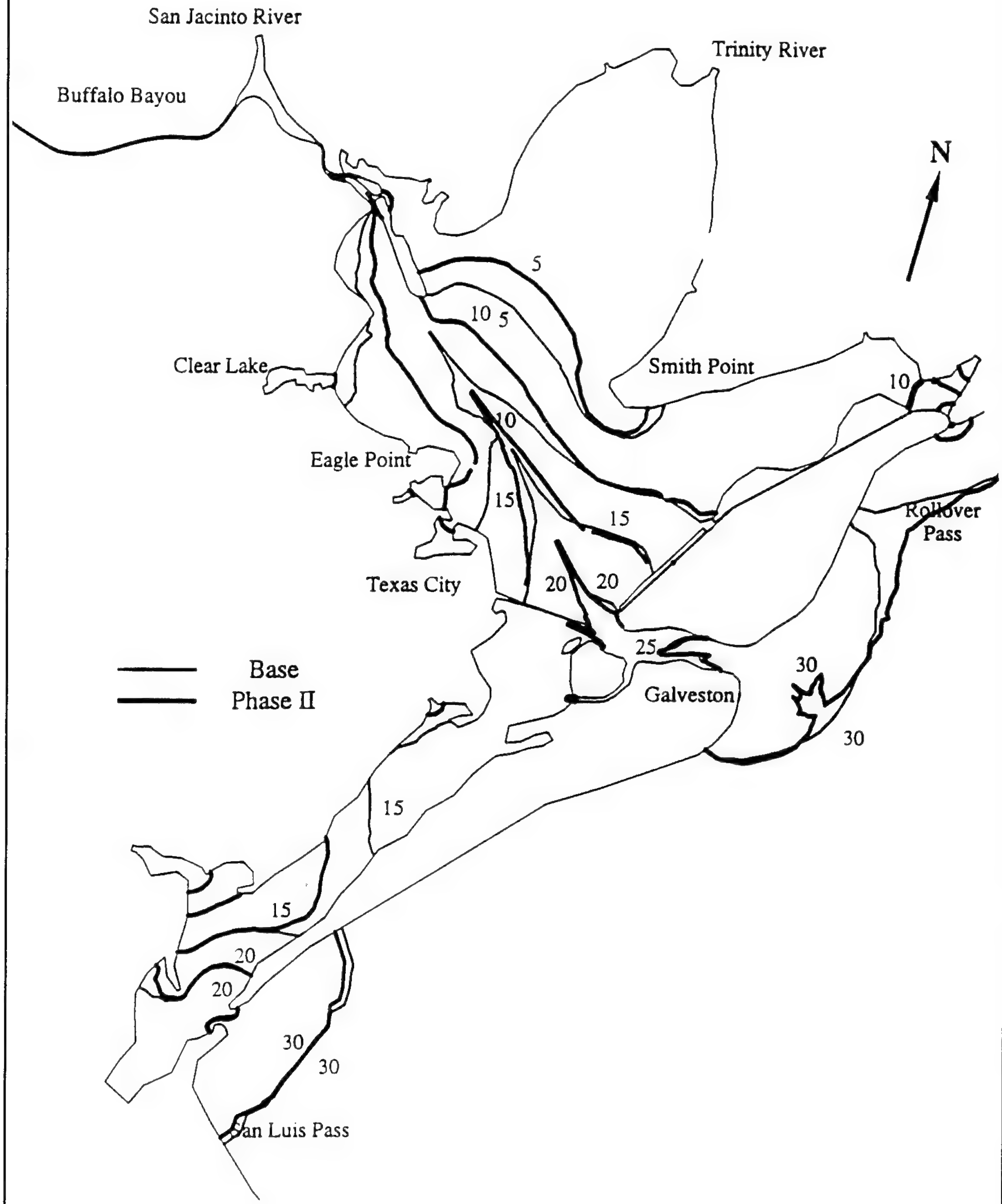
JUNE 2049, PHASE II
MEDIUM FLOW, BOTTOM



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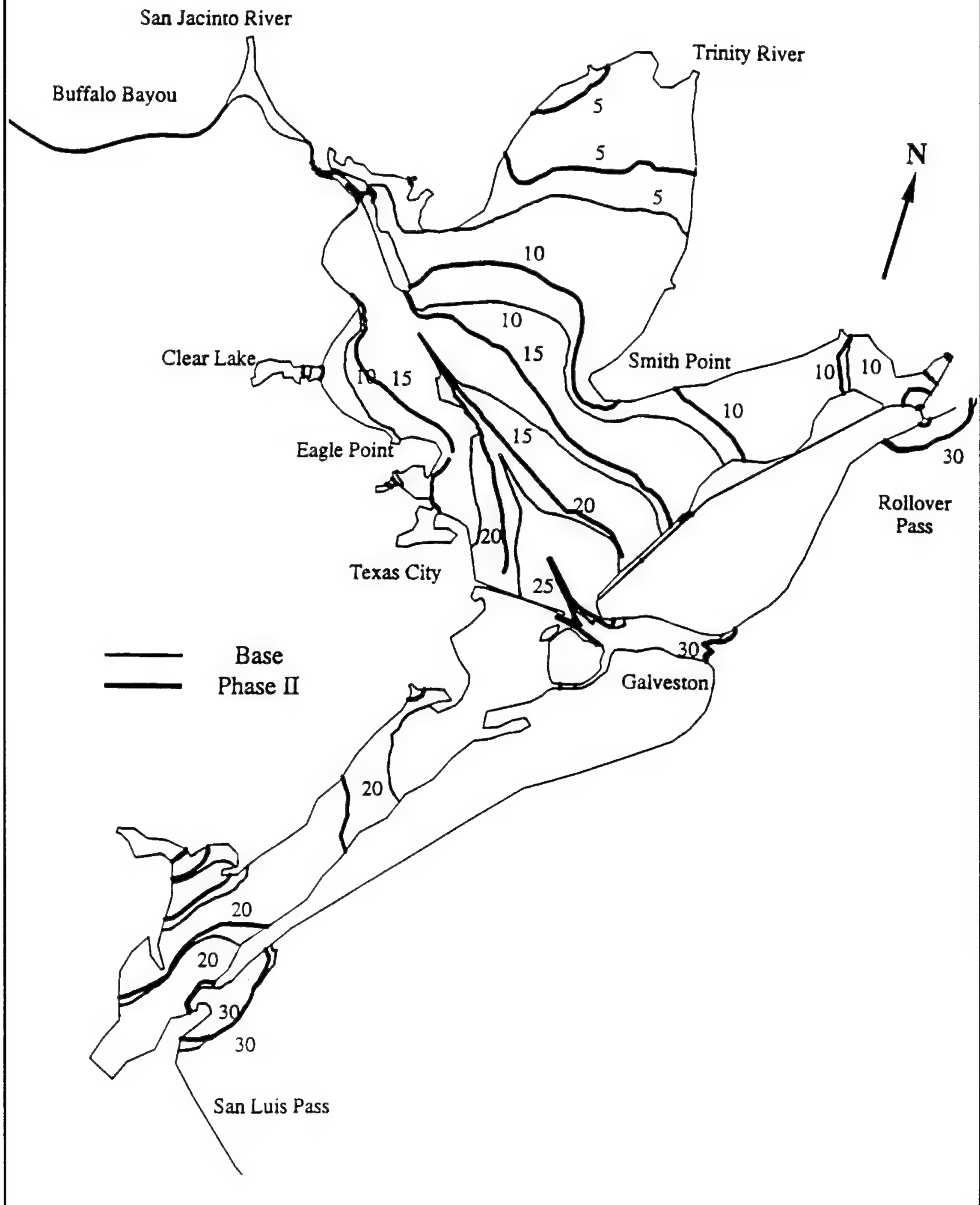
JULY 2049, PHASE II
MEDIUM FLOW, BOTTOM



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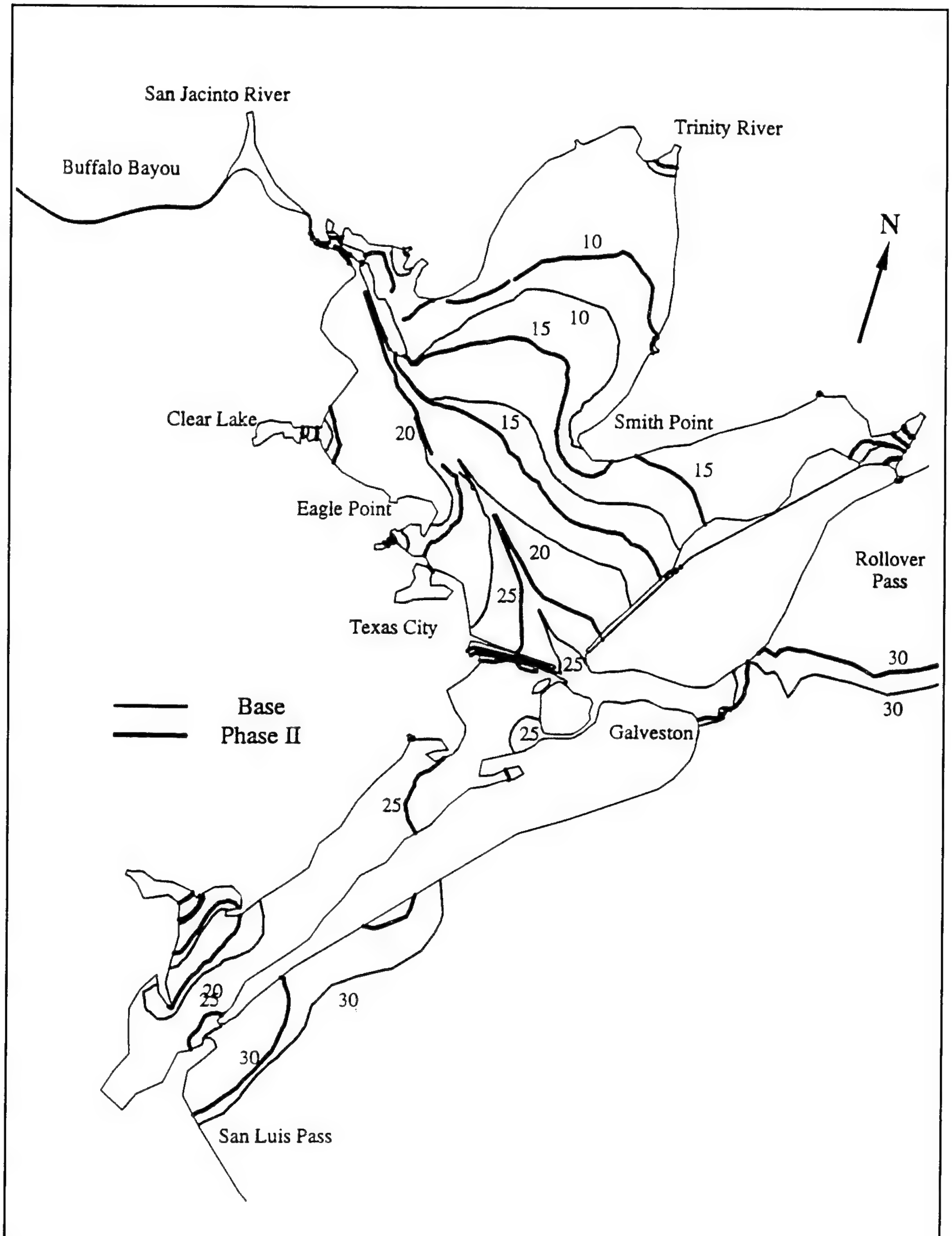
AUGUST 2049, PHASE II
MEDIUM FLOW, BOTTOM



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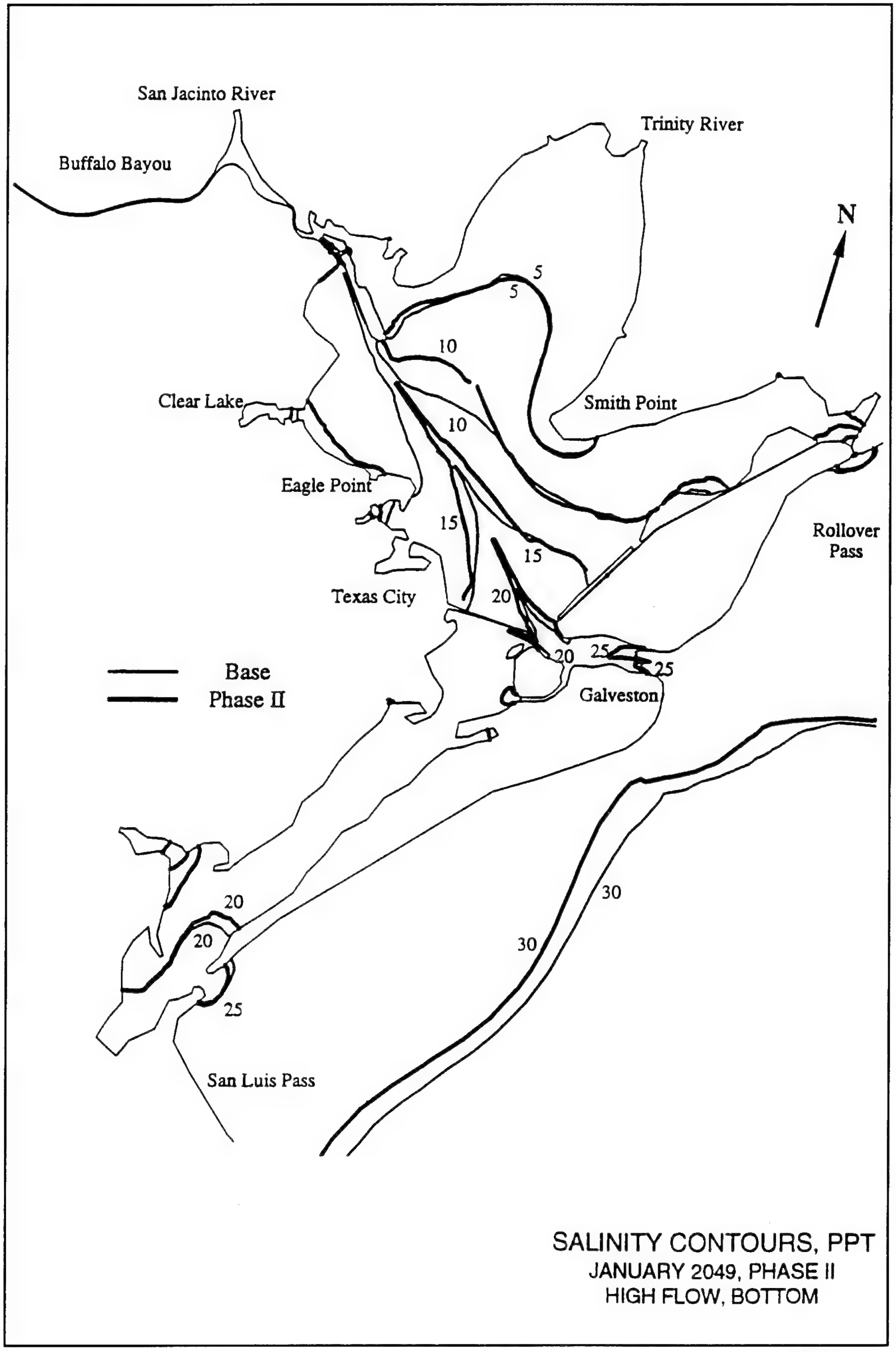
SEPTEMBER 2049, PHASE II
MEDIUM FLOW , BOTTOM



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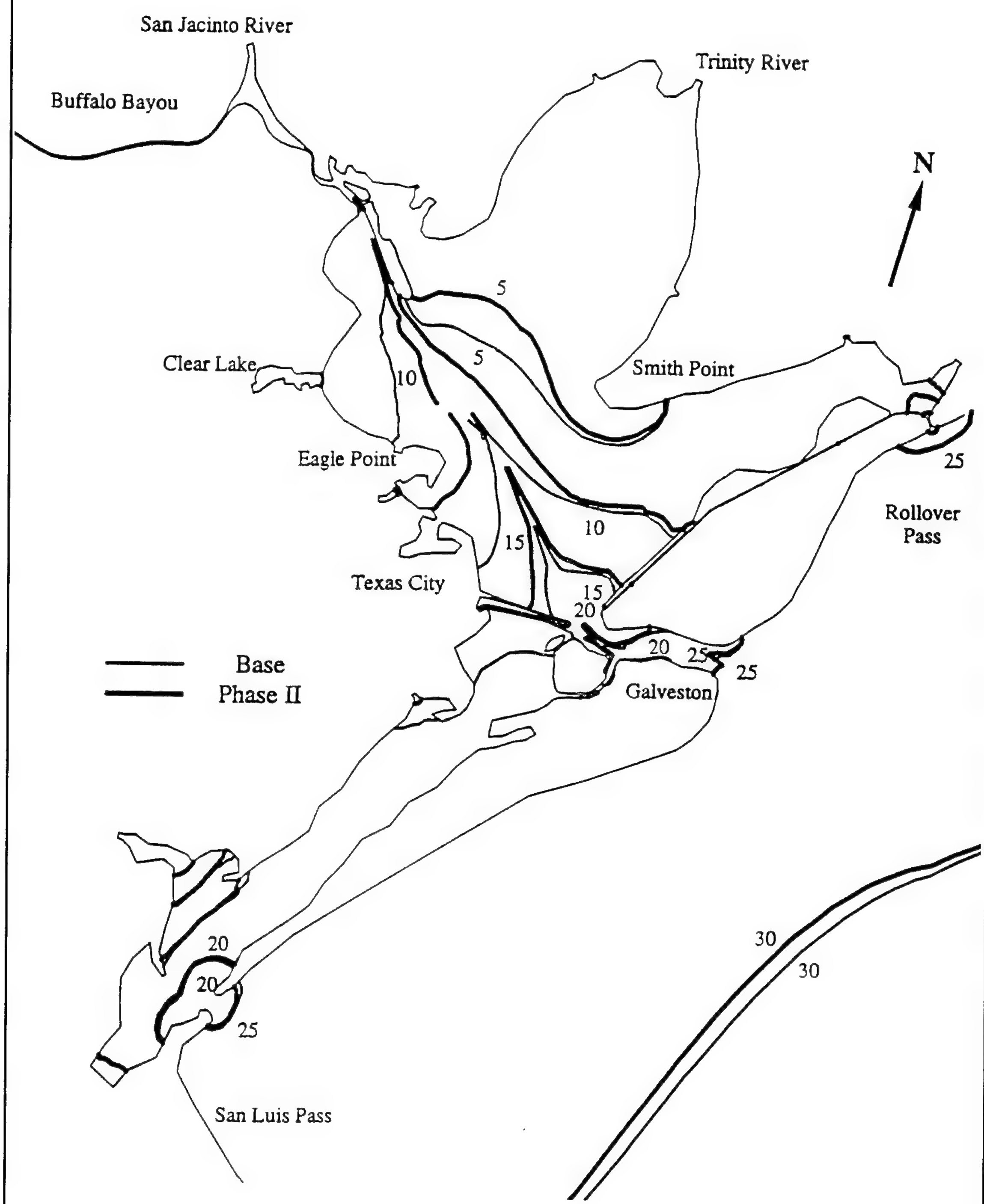
JANUARY 2049, PHASE II
HIGH FLOW, BOTTOM



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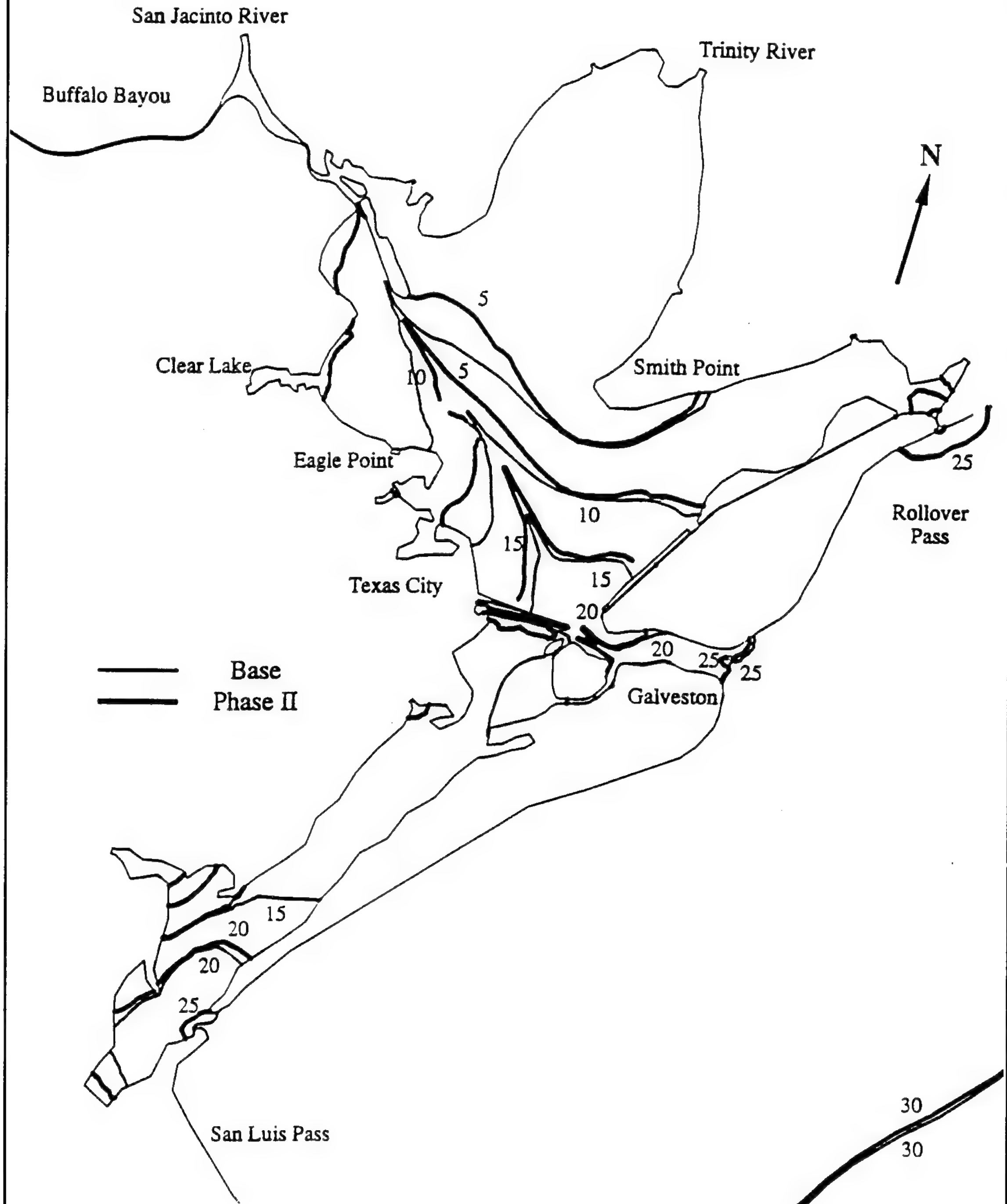

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MARCH 2049, PHASE II
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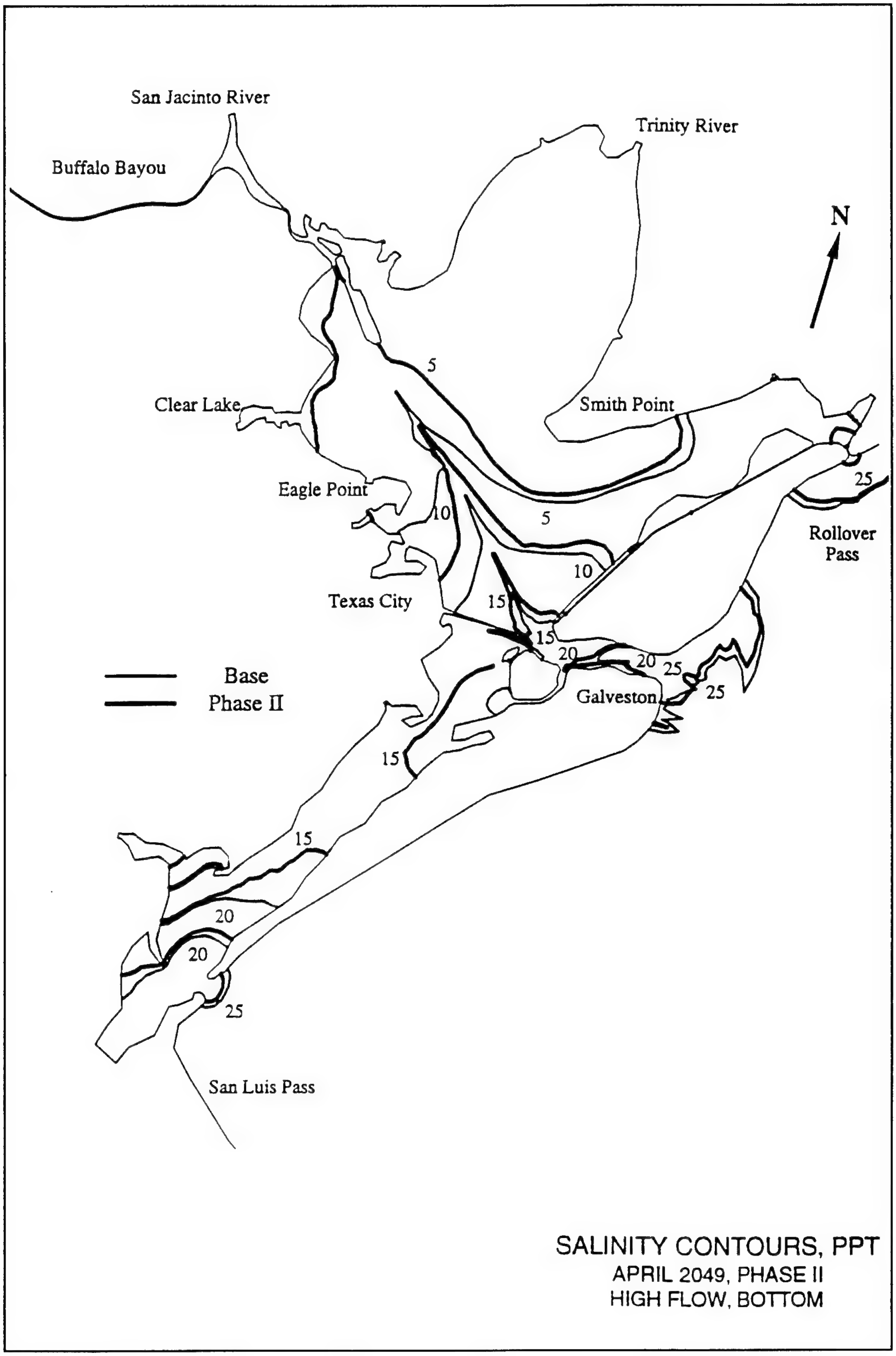
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APRIL 2049, PHASE II
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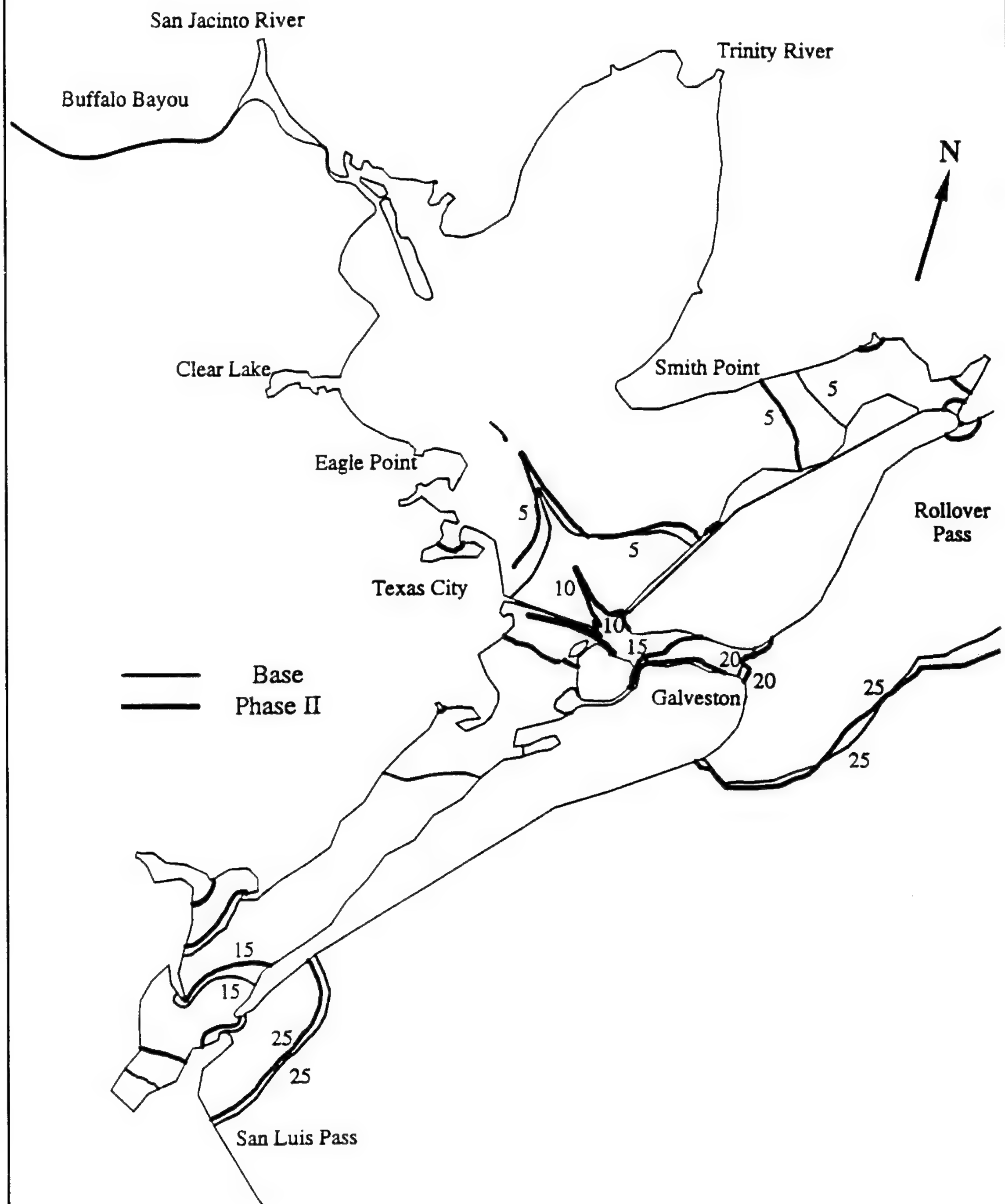

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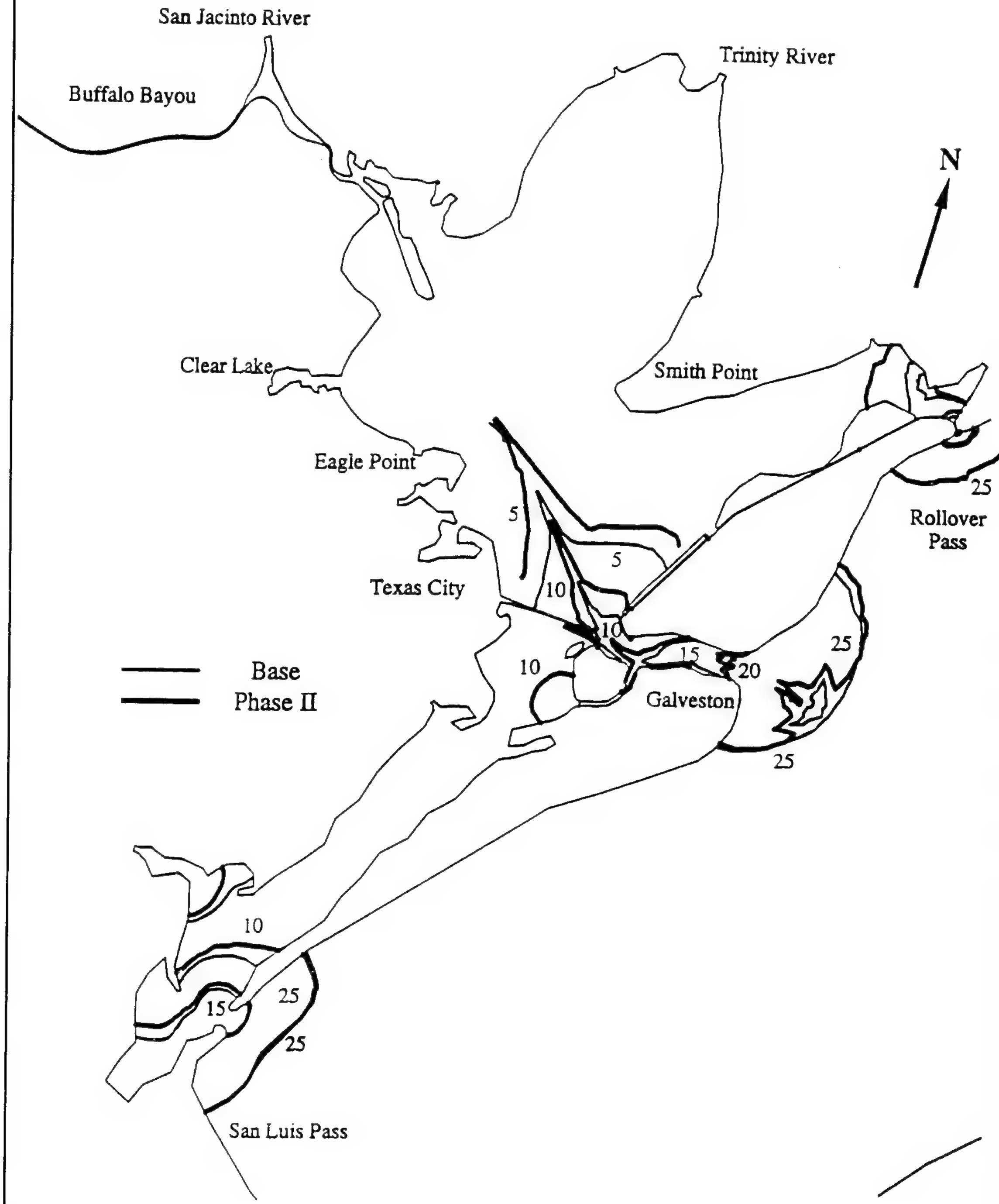
HIGH FLOW, BOTTOM



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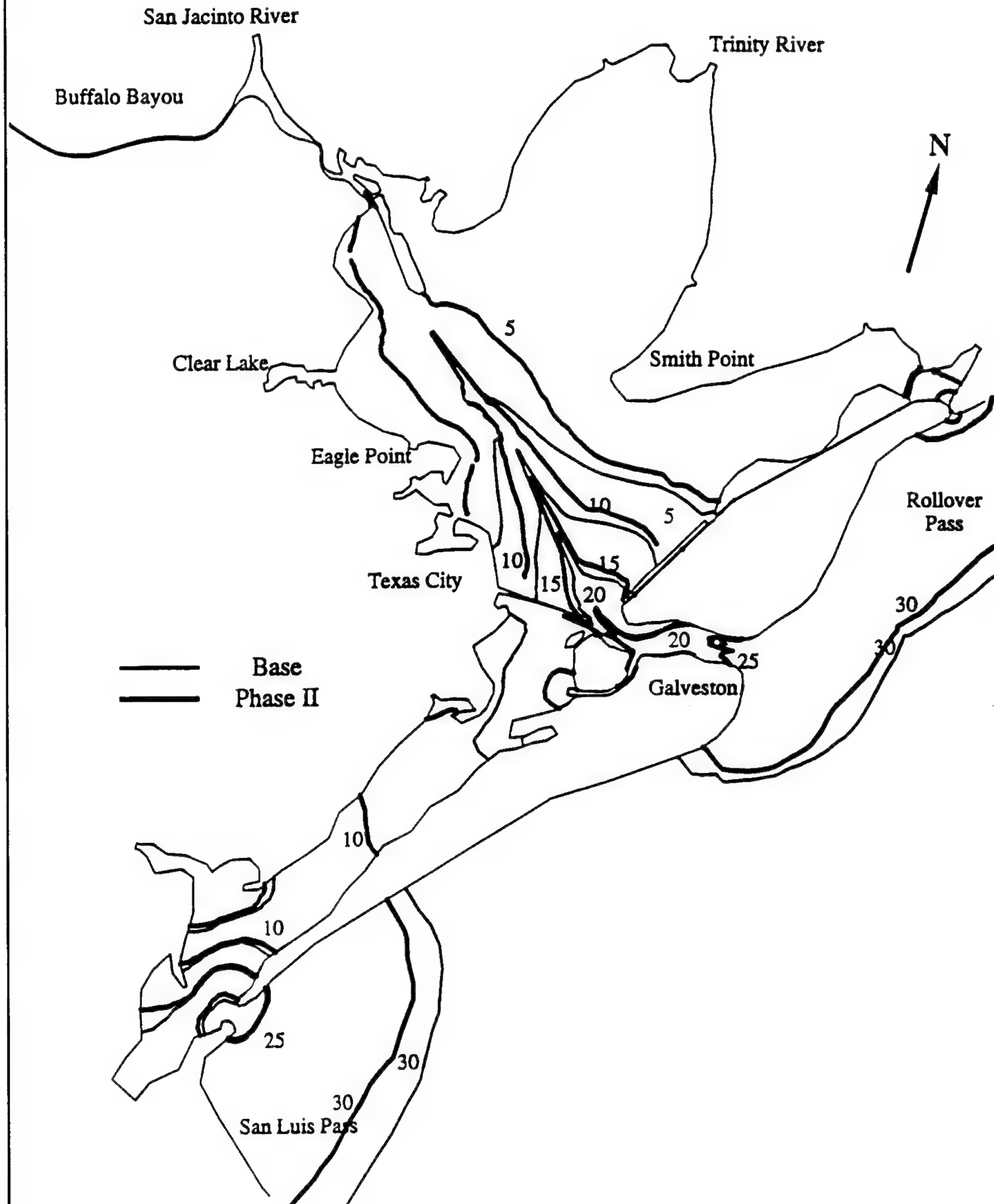

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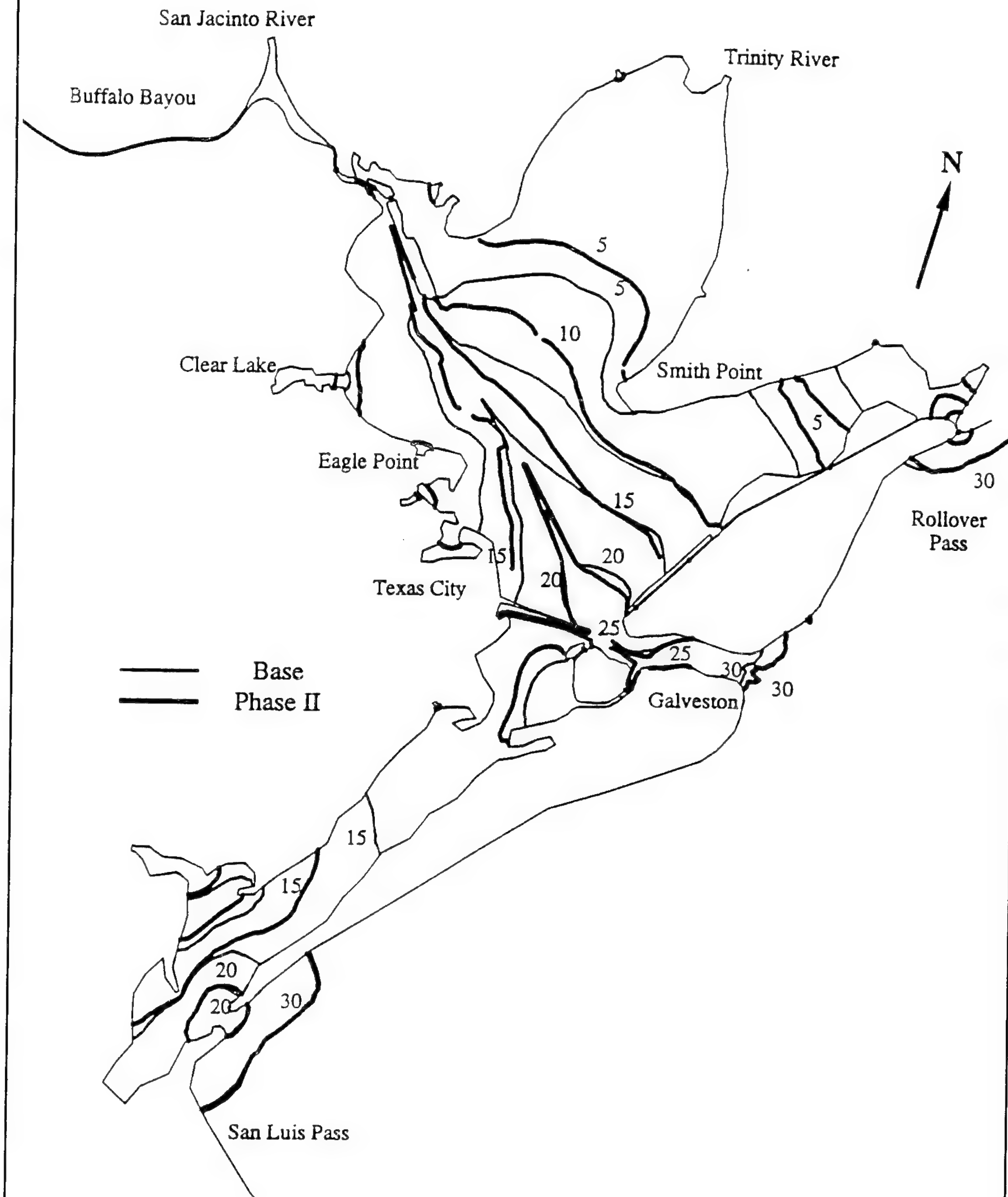
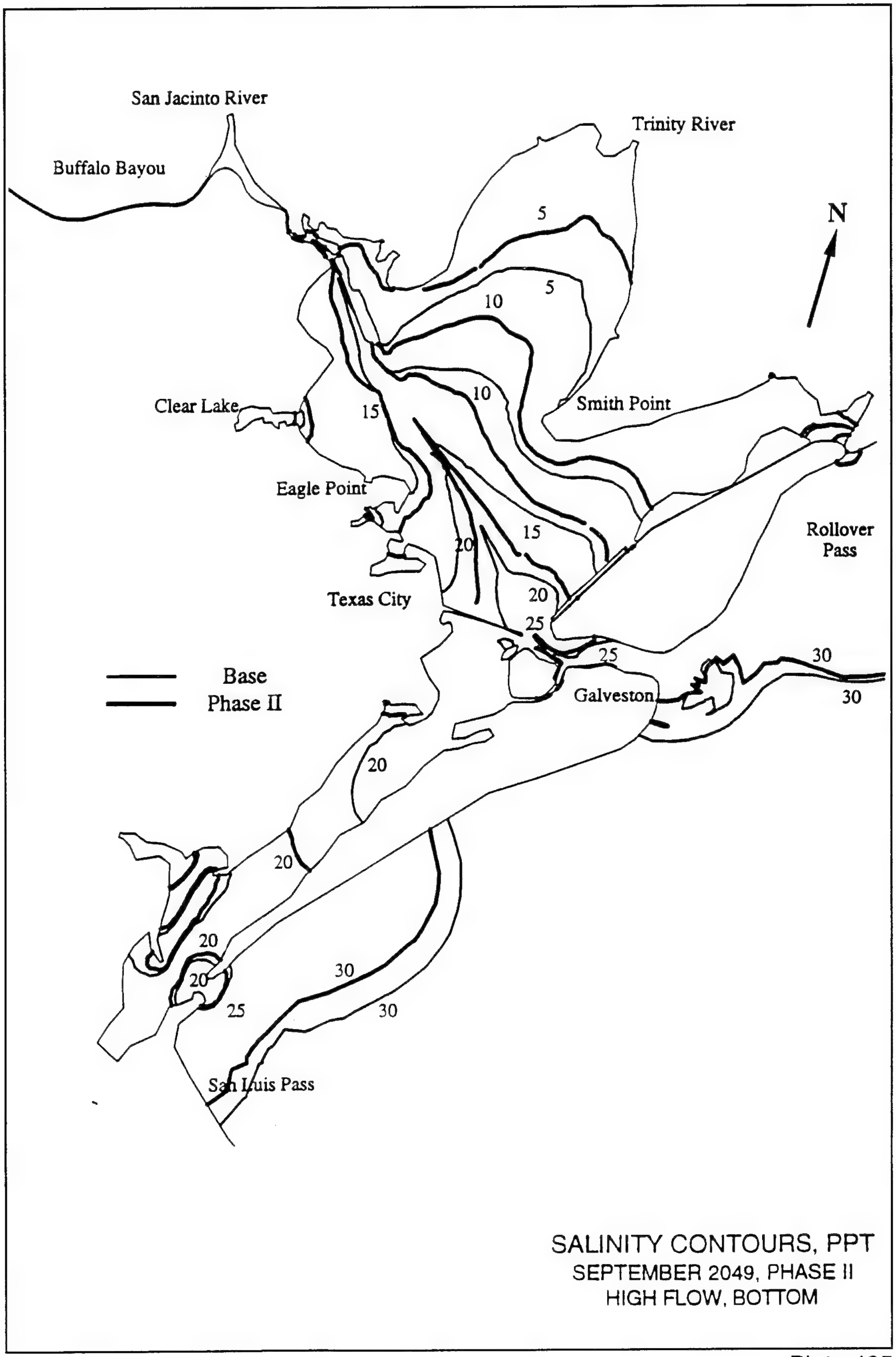


SALINITY CONTOURS, PPT
AUGUST 2049, PHASE II
HIGH FLOW, BOTTOM

Plate 424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SEPTEMBER 2049, PHASE II
HIGH FLOW, BOTTOM

Appendix A
The Hydrodynamic Code

The geometric complexity of this estuary, with its navigation channel, multiple inlets, and many proposed disposal islands, requires a numerical model that relies upon an unstructured computational mesh. The code chosen is the Galerkin-based finite element model RMA10-WES, which is a U.S. Army Engineer Waterways Experiment Station (WES) adaptation of the RMA-10 code developed by King (1993). This code computes time-varying open-channel flow and salinity/temperature transport in 1, 2, and 3 dimensions. It invokes the hydrostatic pressure and mild slope assumption. Vertical turbulence is supplied using a Mellor-Yamada Level II (Mellor and Yamada 1982) k-ℓ approach modified for stratification by the method of Henderson-Sellers (1984). The salinity/density relationship is based upon Pritchard (1982).

The full three-dimensional equations are reduced to a set of two momentum equations, an integrated continuity equation, a convection-diffusion equation, and an equation of state. The simplification is a result of the hydrostatic pressure approximation.

$$\rho \frac{Du}{Dt} - \nabla \cdot \sigma_x + \frac{\partial P}{\partial x} - \Gamma_x = 0 \tag{A1}$$

$$\rho \frac{Dv}{Dt} - \nabla \cdot \sigma_y + \frac{\partial P}{\partial y} - \Gamma_y = 0 \tag{A2}$$

$$\frac{\partial h}{\partial t} + u_\zeta \frac{\partial \zeta}{\partial x} - u_a \frac{\partial a}{\partial x} + v_\zeta \frac{\partial \zeta}{\partial y} - v_a \frac{\partial a}{\partial y} + \int_a^\zeta \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) dz = 0 \tag{A3}$$

$$\frac{Ds}{Dt} - \frac{\partial}{\partial x}\left(D_x \frac{\partial s}{\partial x}\right) - \frac{\partial}{\partial y}\left(D_y \frac{\partial s}{\partial y}\right) - \frac{\partial}{\partial z}\left(D_z \frac{\partial s}{\partial z}\right) = 0 \tag{A4}$$

$$\rho = F(s) \tag{A5}$$

Elevation-related terms are defined in Figure A1.

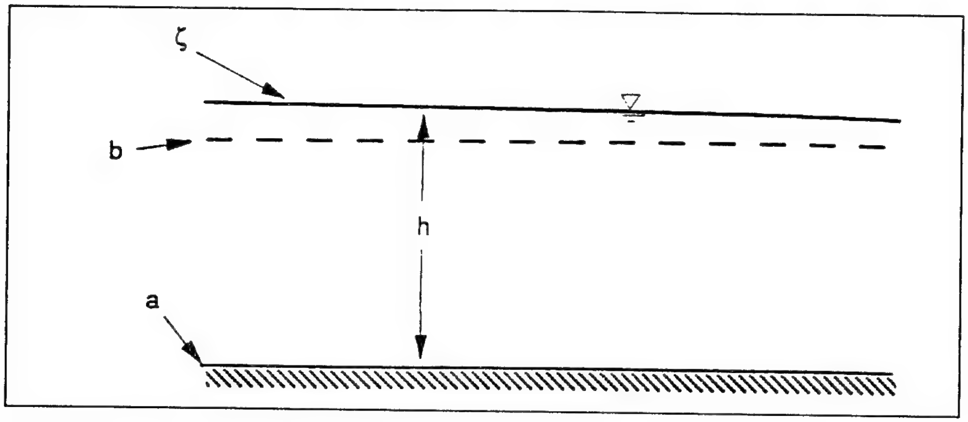

Figure A1. Definitions for elevation terms

where

$$\sigma_x = \begin{Bmatrix} E_{xx} \dfrac{\partial u}{\partial x} \\ E_{xy} \dfrac{\partial u}{\partial y} \\ E_{xz} \dfrac{\partial u}{\partial z} \end{Bmatrix} \quad ; \quad \sigma_y = \begin{Bmatrix} E_{yx} \dfrac{\partial v}{\partial x} \\ E_{yy} \dfrac{\partial v}{\partial y} \\ E_{yz} \dfrac{\partial v}{\partial z} \end{Bmatrix}$$

and

ρ = density

u,v,w = x,y,z velocity components

t = time

P = pressure

$$\Gamma_x = \rho \Omega v - \frac{\rho g u_a (u_a^2 + v_a^2)^{(1/2)}}{C^2} + \psi\ W^2 \cos\ (\Theta)$$

$$\Gamma_y = -\rho \Omega u - \frac{\rho g v_a (u_a^2 + v_a^2)^{(1/2)}}{C^2} + \psi\ W^2 \sin\ (\Theta)$$

$\Omega = 2\omega \sin(\phi)$

ω = rate of angular rotation of the earth

ϕ = local latitude

g = gravitational acceleration

C = Chezy or Manning friction formulation

ψ = a coefficient from Wu (1980)

W = wind speed

Θ = wind direction counterclockwise from easterly

h = depth

u_ζ, v_ζ = x,y velocity components at the water surface

ζ = water surface elevation

u_a, v_a = x,y velocity

a = bed elevation

s = salinity
D_x, D_y, D_z = diffusion coefficient for salt
E = eddy viscosity components

The continuity equation

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \tag{A6}$$

is solved as a second part of each solution step. Equation A6 is converted to an appropriate boundary value problem through differentiation with respect to z. After rearrangement it takes the form

$$\frac{\partial^2 w}{\partial z^2} = - \frac{\partial}{\partial z}\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) \tag{A7}$$

subject to boundary conditions specified for the water surface and the bed.

$$w_\zeta = u_\zeta \frac{\partial \zeta}{\partial x} + v_\zeta \frac{\partial \zeta}{\partial y} + \frac{\partial h}{\partial t} \quad \text{at the water suface} \tag{A8}$$

and

$$w_a = u_a \frac{\partial a}{\partial x} + v_a \frac{\partial a}{\partial y} \quad \text{at the bed} \tag{A9}$$

Note that in these equations the values of u and v will be known at all locations from the previous part of the solution step. Values of w in this solution are used in the next iteration for u,v,h, and s.

The geometric system varies with time; i.e., the water depth h varies during the simulation. In order to develop an Eulerian form for the solution, it is desirable to transform this system to one that can be described with a constant geometric structure. Early development of the model (King 1982) used a σ-transformation in which the bed and the water surface are transformed to constants. In a later analysis of this method, King (1985) pointed out that at locations where a sharp break in bottom profile occurs, the transformation is not unique and momentum in the component directions may not be correctly preserved. An alternative transformation that preserves the bottom profile as defined, but transforms the water surface to a constant elevation is now used ($z^\blacktriangledown$ transformation).

This transformation is defined by:

$$x^\blacktriangledown = x \tag{A10}$$

$$y^{\triangledown} = y \tag{A11}$$

$$z^{\triangledown} = a + (z - a)\frac{(b - a)}{h} \tag{A12}$$

where b is the fixed vertical location to which the water surface will be transformed. Equations A1-A6 and A7-A9 then incorporate the transformation (A10-A12).

Another advantage of this transformation is that it produces $z^{\triangledown}$ = constant lines that are close to horizontal, i.e., z = constant lines. This results in less fictitious density-driven currents near bed profile breaks (Stelling and van Kester 1993). Since stratification-related phenomena are usually nearly horizontal, it is important that the transformation leave constant surfaces that are nearly horizonal. Considering the pressure gradient (due to the density gradient) in this transformation produces

$$\frac{\partial P}{\partial x} = \frac{\partial P}{\partial x^{\triangledown}} + \frac{\partial P}{\partial z^{\triangledown}}\,\frac{\partial z^{\triangledown}}{\partial x} \tag{A13}$$

In a strongly stratified stagnant system this pressure gradient should be zero. However, note that Equation A13 in the transformed system is dependent upon two terms (each of which could be large) to cancel each other. This could cause artificial currents due to truncation and roundoff error. A transformation in which $\partial z^{\triangledown}/\partial x \approx 0$, i.e., $z^{\triangledown} \approx z$, will reduce this problem. Figure A2 shows an example for a case similar to the Galveston project in which a 40-ft-deep channel passes through an 8-ft-deep bay. Here b is chosen to be an elevation of 0 and ζ is 2 ft. Near the break in the bed profile $\partial z^{\triangledown}/\partial x$ is fairly small, or $z^{\triangledown}$ surfaces are nearly horizontal. Contrast this with the σ transformation in Figure A3. The σ = constant surfaces are far from horizontal along the channel side slopes. The truncation and roundoff errors tend to drive fictitious currents that cause the denser salt water to leave the channel. The $z^{\triangledown}$ transformation results in

$$\frac{\partial z^{\triangledown}}{\partial x} = 0(\zeta - b) \tag{A14}$$

whereas the σ transformation is

$$\frac{\partial \sigma}{\partial x} = 0(h) \tag{A15}$$

which is much larger.

The Galerkin finite element approximation of Equations A1-A4 and A7 uses a quadratic approximation for u,v,w, and s and linear for h and P. The

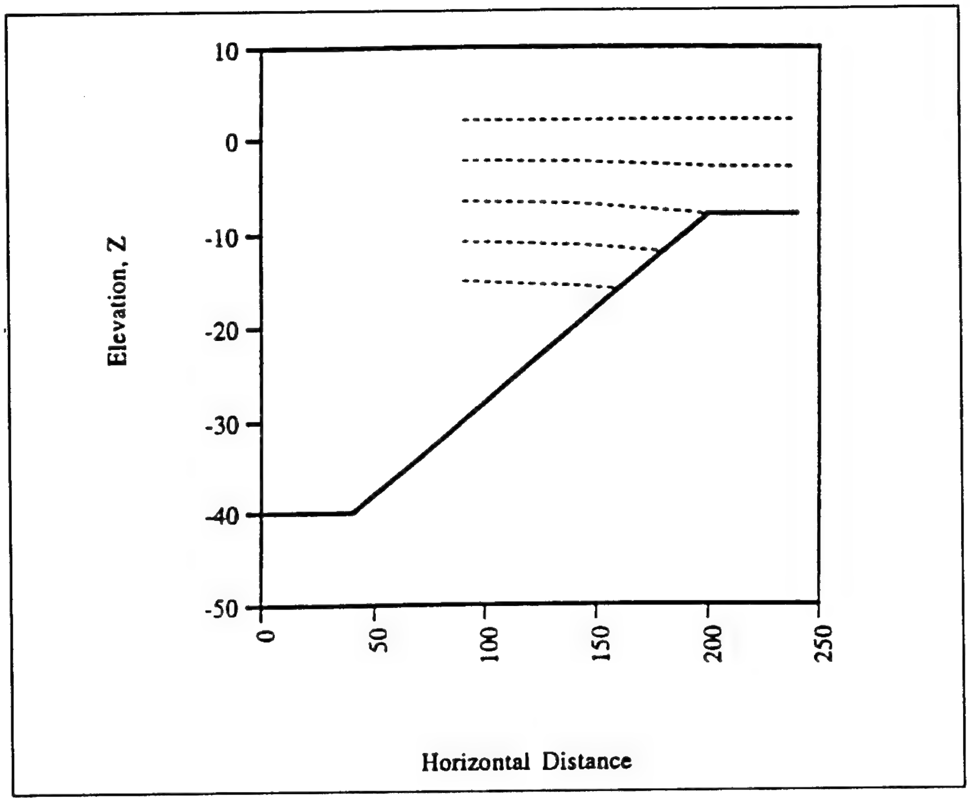

Figure A2. Lines of constant $z^{\triangledown}$ near a significant grade change

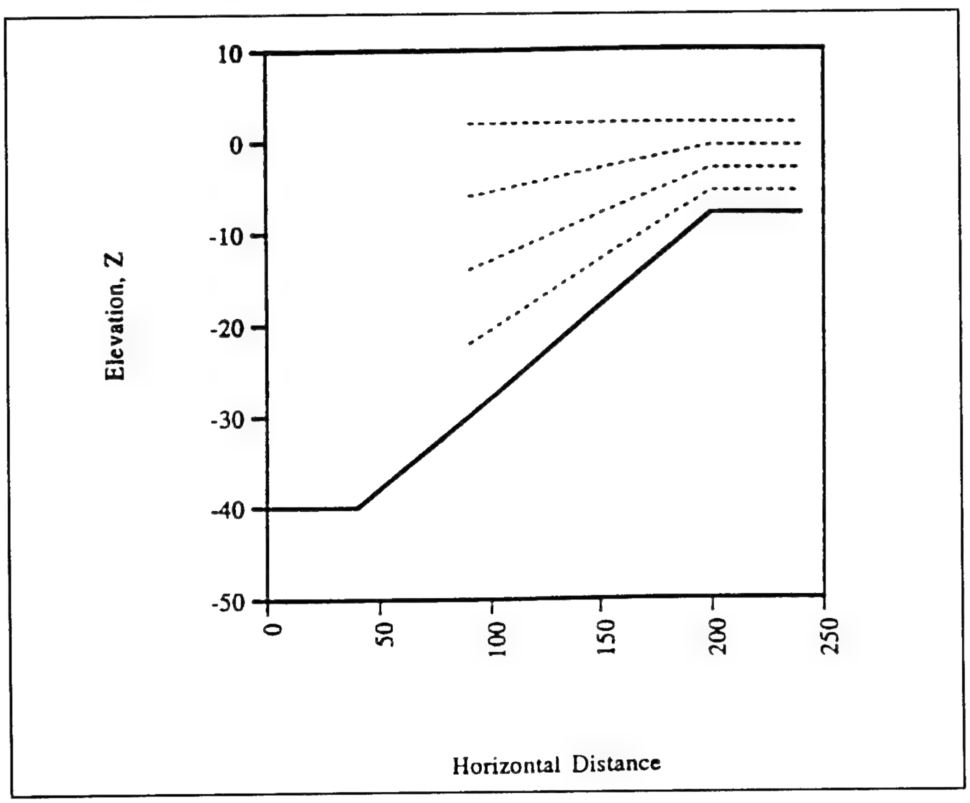

Figure A3. Lines of constant σ near a significant grade change

nonlinearity is addressed by Newton-Raphson iteration at each time-step. Generally the iteration process is split into calculation of Equations A1-A3, then A7, followed by A4. This sequence is repeated until sufficient convergence is reached.

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Appendix B
Tabulation of Freshwater Inflows

Table B1
Present Hydrology

Column	Name	Volume, acre-ft											
		January	February	March	April	May	June	July	August	September	October	November	December
							Low Flow						
1	Chocolate Bayou	13,135.0	15,298.3	5,514.8	6,812.4	8,515.1	8,186.3	16,512.1	1,0197.9	22,685.3	6,784.4	9,376.0	9,749.9
2	Highland Bayou	1,278.6	1,177.2	471.1	539.8	561.3	453.7	1,447.8	1,098.2	1,953.0	497.0	666.6	902.2
3	Oyster Bayou	14,170.0	13,381.3	5,504.1	7,313.7	8,073.5	9,833.4	7,284.7	7,775.8	17,560.6	6,415.2	10,191.3	18,752.1
4	Robinson Bayou	3,879.9	3,575.8	1,543.3	2,536.4	2,450.2	2,989.6	2,150.9	2,171.6	4,959.2	1,623.9	2,845.8	4,787.9
5	Trinity River	154,216.5	274,008.9	171,443.6	265,548.6	235,460.0	179,220.0	75,906.9	68,462.6	64,583.5	56,267.2	123,715.7	285,082.3
6	Cedar Bayou	7,221.0	8,639.0	3,500.6	4,814.6	5,019.8	7,252.4	4,832.2	5,050.0	8,824.6	3,522.2	6,942.4	9,116.4
7	San Jacinto River	56,154.4	88,329.6	36,931.3	62,327.5	55,901.8	33,005.0	15,698.4	16,499.5	29,146.0	14,678.8	34,729.4	79,721.1
8	Buffalo Bayou	51,305.3	56,221.8	25,582.4	37,007.9	37,902.8	30,831.1	25,649.5	41,421.8	49,264.4	24,876.4	36,089.5	59,446.2
9	Clear Creek	9,611.1	11,718.6	4,889.7	5,479.1	7,036.6	8,189.8	10,146.3	8,254.2	14,969.2	5,022.1	8,342.3	8,869.3
10	Dickinson Bayou	7,258.6	7,870.0	3,442.7	4,658.4	5,038.7	4,565.3	8,022.5	6,826.3	11,740.0	3,804.8	5,409.7	6,805.6
11	Live Oak Bayou	5,713.7	5,224.4	2,184.1	3,714.6	3,553.2	4,435.6	3,159.7	3,330.9	7,117.3	2,449.0	4,179.3	7,081.1
							Medium Flow						
1	Chocolate Bayou	37,138.5	32,270.3	18,427.1	14,385.1	33,599.5	29,844.7	54,028.1	23,110.6	47,819.4	32,166.0	24,920.9	18,096.6
2	Highland Bayou	3,615.2	2,483.2	1,574.2	1,139.9	2,214.8	1,653.9	4,737.2	2,488.8	4,116.8	2,356.2	1,771.8	1,674.5
3	Oyster Bayou	40,065.0	28,226.5	18,391.4	15,443.8	31,857.2	35,849.5	23,835.9	17,621.6	37,016.8	30,415.3	27,087.7	34,805.3
4	Robinson Bayou	10,970.2	7,542.8	5,156.9	5,355.8	9,668.4	10,899.2	7,037.6	4,921.4	10,453.7	7,699.1	7,564.0	8,886.7
5	Trinity River	436,040.4	577,994.6	572,857.1	560,735.0	929,100.6	653,381.3	248,369.2	155,150.5	136,138.8	26,6771.0	328,827.6	529,134.9
6	Cedar Bayou	20,417.2	18,223.1	11,696.9	10,166.7	19,807.7	26,439.9	15,811.2	11,444.4	18,601.9	16,699.2	18,452.5	16,920.8
7	San Jacinto River	158,774.2	186,322.6	123,401.3	131,611.4	220,582.6	120,325.9	51,365.5	37,391.2	61,438.3	69,594.4	92,308.2	147,968.6
8	Buffalo Bayou	145,063.5	118,594.3	85,480.5	78,146.3	149,560.5	112,400.7	83,925.8	93,870.5	103,846.8	117,942.6	95,923.8	110,336.7
9	Clear Creek	27,175.0	24,719.3	16,338.4	11,569.7	27,765.8	29,857.4	33,199.1	18,705.7	31,554.4	23,810.8	22,173.3	16,462.1
10	Dickinson Bayou	20,523.4	16,601.1	11,503.3	9,836.6	19,882.1	16,643.7	26,249.8	15,469.8	24,747.4	18,039.2	14,378.5	12,631.6
11	Live Oak Bayou	16,155.3	11,020.3	7,297.9	7,843.7	14,020.7	16,170.7	10,338.5	7,548.6	15,002.8	11,611.3	11,108.2	13,143.1

(Continued)

Table B1 (Concluded)

Column	Name	Volume, acre-ft											
		January	February	March	April	May	June	July	August	September	October	November	December
High Flow													
1	Chocolate Bayou	63,063.6	38,156.2	35,944.1	36,689.8	59,846.4	68,223.0	114,171.6	32,416.1	101,753.2	48,628.9	47,361.0	17,0771.1
2	Highland Bayou	6,138.8	2,936.1	3,070.6	2,907.3	3,944.9	3,780.8	10,010.6	3,490.9	8,760.0	3,562.1	3,367.2	1,580.2
3	Oyster Bayou	68,032.8	33,374.9	35,874.4	39,389.9	56,742.9	81,949.4	50,369.7	24,717.0	78,766.7	45,982.1	51,479.0	32,844.5
4	Robinson Bayou	18,628.1	8,918.5	10,059.0	13,660.2	17,221.0	24,914.8	14,871.9	6,903.0	22,244.0	11,639.5	14,375.1	8,386.1
5	Trinity River	740,424.1	683,418.5	1,117,419.5	1,430,173.2	1,654,883.8	1,493,584.7	524,851.1	217,621.9	289,684.9	403,306.5	624,922.7	499,326.3
6	Cedar Bayou	34,669.6	21,546.9	22,816.1	25,930.4	35,280.9	60,439.8	33,412.1	16,052.5	39,582.3	25,246.0	35,068.2	15,967.5
7	San Jacinto River	269,608.5	220,307.0	240,707.6	335,679.2	392,894.6	275,056.8	108,545.0	52,446.8	130,732.4	105,213.3	175,427.8	139,632.9
8	Buffalo Bayou	246,326.9	140,225.4	166,738.9	199,314.8	266,392.3	256,940.3	177,351.1	131,667.5	220,972.0	178,306.5	182,298.1	104,120.9
9	Clear Creek	46,144.8	29,228.0	31,869.8	29,508.9	49,455.6	68,251.9	70,156.0	26,237.6	67,143.5	35,997.3	42,139.4	15,534.7
10	Dickinson Bayou	34,850.1	19,629.0	22,438.5	25,088.6	35,413.4	38,046.4	55,470.7	21,698.7	52,659.1	27,271.7	27,325.7	11,920.0
11	Live Oak Bayou	27,432.7	13,030.3	14,235.4	20,005.7	24,973.2	36,965.1	21,847.2	10,588.0	31,924.0	17,554.1	21,110.7	12,402.7

Table B2
1999 Hydrology

Column	Name	Volume, acre-ft January	February	March	April	May	June	July	August	September	October	November	December
							Low Flow						
1	Chocolate Bayou	13,515.6	15,642.0	5,894.6	7,180.3	8,895.7	2,554.6	16,892.7	10,578.5	23,053.6	7,165.0	9,744.3	10,130.5
2	Highland Bayou	1,278.6	1,177.2	471.1	539.8	5,61.3	453.7	1,447.8	1,098.2	1,953.0	497.0	666.6	902.2
3	Oyster Bayou	14,170.0	13,381.3	5,504.1	7,313.7	9,073.5	9,833.4	7,284.7	7,775.8	17,560.0	6,415.2	10,191.3	18,752.1
4	Robinson Bayou	3,879.9	3,575.8	1,543.3	2,536.4	2,450.2	2,989.6	2,150.9	2,171.6	4,959.2	1,623.9	2,845.8	4,787.9
5	Trinity River	129,480.4	251,666.6	146,707.5	241,610.4	206,918.3	151,600.0	42,608.2	35,164.0	36,962.5	31,531.1	99,777.5	260,346.2
6	Cedar Bayou	10,560.4	11,655.2	6,840.0	8,046.3	8,872.9	10,981.1	9,327.5	9,545.3	12,553.4	6,861.6	10,174.1	12,455.8
7	San Jacinto River	55,583.6	87,814.0	36,360.5	61,775.1	55,331.0	32,452.6	15,127.6	15,928.7	28,593.6	14,108.0	34,177.0	79,150.3
8	Buffalo Bayou	64,316.5	67,973.9	38,593.6	49,599.4	52,915.7	45,359.2	43,164.6	58,936.9	63,793.0	37,887.6	48,681.0	72,457.4
9	Clear Creek	13,049.4	14,824.2	8,328.0	8,806.5	11,003.9	12,029.0	14,774.8	12,882.7	18,808.5	8,460.4	11,669.7	12,307.6
10	Dickinson Bayou	7,943.6	8,488.7	4,127.7	5,321.3	5,723.7	5,228.2	8,707.5	7,511.3	12,402.9	4,489.8	6,072.6	7,490.6
11	Live Oak Bayou	5,713.7	5,224.4	2,184.1	3,714.6	3,553.2	4,435.6	3,159.7	3,330.9	7,117.3	2,449.0	4,179.3	7,081.1
							Medium Flow						
1	Chocolate Bayou	37,138.5	32,270.3	18,427.1	14,385.1	33,599.5	29,844.7	54,028.1	23,110.6	47,819.4	32,166.0	24,920.9	18,096.6
2	Highland Bayou	3,615.2	2,483.2	1,574.2	1,139.9	2,214.8	1,653.9	4,737.2	2,488.8	4,116.8	2,356.2	1,771.8	1,674.5
3	Oyster Bayou	40,065.0	28,226.5	18,391.4	15,443.8	31,857.2	35,849.5	23,835.9	17,621.6	37,016.8	30,415.3	27,087.7	34,805.3
4	Robinson Bayou	10,970.2	7,542.8	5,156.9	5,355.8	9,668.4	10,899.2	7,037.6	4,921.4	10,453.7	7,699.1	7,564.0	8,886.7
5	Trinity River	411,304.4	555,652.3	548,121.0	536,796.8	00,558.9	625,761.3	215,070.5	121,851.8	108,517.8	242,034.9	304,889.4	504,398.8
6	Cedar Bayou	23,756.6	21,239.3	15,036.3	13,398.4	23,460.8	30,168.6	20,306.5	15,939.7	22,330.7	20,038.6	21,684.2	20,260.2
7	San Jacinto River	158,774.2	186,322.6	123,401.3	131,611.4	220,582.6	120,325.9	51,365.5	37,391.2	61,438.3	69,594.4	92,308.2	147,968.6
8	Buffalo Bayou	158,074.7	130,346.4	98,491.7	90,737.8	164,573.4	126,928.8	101,440.9	111,385.6	118,175.4	130,953.8	108,514.8	,233,347.9
9	Clear Creek	30,613.3	27,824.0	19,776.7	14,897.1	31,733.1	33,696.0	37,827.6	23,334.2	35,393.7	27,249.1	25,500.7	19,900.4
10	Dickinson Bayou	20,523.4	16,601.1	11,503.3	9,836.6	19,882.1	16,643.7	26,249.8	15,469.8	24,747.4	18,039.2	14,378.5	12,631.6
11	Live Oak Bayou	16,155.3	11,020.3	7,297.9	7,843.7	14,020.7	16,170.7	10,338.5	7,548.6	15,002.8	11,611.3	11,108.2	13,143.1

(Continued)

Table B2 (Concluded)

Column	Name	Volume, acre-ft											
		January	February	March	April	May	June	July	August	September	October	November	December
		High Flow											
1	Chocolate Bayou	63,063.6	38,156.2	35,944.1	36,689.8	59,846.4	68,223.0	114,171.6	32,416.1	101,753.2	48,628.9	47,361.0	17,077.1
2	Highland Bayou	6,138.8	2,936.1	3,070.6	2,907.3	3,944.9	3,780.8	10,010.6	3,490.9	8,760.0	3,562.1	3,367.2	1,580.2
3	Oyster Bayou	68,032.8	33,374.9	35,874.4	39,389.9	56,742.9	81,949.4	50,369.7	24,717.0	78,766.7	45,982.1	51,479.0	32,844.5
4	Robinson Bayou	18,628.1	8,918.5	10,059.0	13,660.2	17,221.0	24,914.8	14,871.9	6,903.0	22,244.0	11,639.5	14,375.1	8,386.1
5	Trinity River	740,424.1	683,418.5	1,117,419.5	1,430,173.2	1,654,883.8	1,493,584.7	524,851.1	217,621.9	289,684.9	403,306.5	624,922.7	499,326.3
6	Cedar Bayou	34,669.6	21,546.9	22,816.1	25,930.4	35,280.9	60,439.8	33,412.1	16,052.5	39,582.3	25,246.0	35,068.2	15,967.5
7	San Jacinto River	269,608.5	220,307.0	240,707.6	335,679.2	392,894.6	275,056.8	108,545.0	52,446.8	130,732.4	105,213.3	175,427.8	139,632.9
8	Buffalo Bayou	246,326.9	140,225.4	166,738.9	199,314.8	266,392.3	256,940.3	177,351.1	131,667.5	220,972.0	178,306.5	182,298.1	104,120.9
9	Clear Creek	46,144.8	29,228.0	31,869.8	29,508.9	49,455.6	68,251.9	70,156.0	26,237.6	67,143.5	35,997.3	42,139.4	15,534.7
10	Dickinson Bayou	34,850.1	19,629.0	22,438.5	25,088.6	35,413.4	38,046.4	55,470.7	21,698.7	52,659.1	27,271.7	27,325.7	11,920.0
11	Live Oak Bayou	27,432.7	13,030.3	14,235.4	20,005.7	24,973.2	36,965.1	21,847.2	10,588.0	31,924.0	17,554.1	21,110.7	12,402.7

Table B3
2024 Hydrology

Column	Name	Volume, acre-ft											
		January	February	March	April	May	June	July	August	September	October	November	December
						Low Flow							
1	Chocolate Bayou	15,947.7	17,777.9	8,437.8	10,031.8	11,920.0	11,628.2	20,176.1	13,602.8	25,794.1	9,782.2	12,114.7	12,562.6
2	Highland Bayou	3,069.8	2,756.2	2,333.0	2,590.2	2,729.5	2,645.5	3,781.0	3,266.4	3,932.7	2,406.0	2,410.6	2,693.4
3	Oyster Bayou	14,292.6	13,489.4	5,631.5	7,454.0	8,221.9	9,983.4	7,444.4	7,924.2	17,695.5	6,345.9	10,310.7	18,874.7
4	Robinson Bayou	3,920.8	3,611.8	1,585.8	2,583.2	2,499.7	3,039.6	2,204.1	2,221.1	5,004.4	1,667.5	2,885.6	4,828.8
5	Trinity River	102,116.4	228,078.5	117,286.9	205,907.7	172,391.4	115,465.9	8,039.6	5,394.0	6,999.1	739.4	72,986.6	232,982.2
6	Cedar Bayou	10,680.7	11,689.0	7,096.9	8,775.1	9,207.9	11,486.0	9,338.9	9,238.1	12,648.5	7,209.5	10,311.1	12,576.1
7	San Jacinto River	65,566.5	96,627.1	46,714.9	73,101.9	67,295.4	44,522.4	27,958.9	27,893.1	39,548.8	24,710.1	43,893.8	89,133.2
8	Buffalo Bayou	72,778.8	75,152.3	47,903.5	61,589.3	63,897.0	57,107.8	53,621.5	67,416.0	72,998.2	47,762.6	56,997.9	80,919.7
9	Clear Creek	15,611.1	17,008.1	11,126.6	12,347.6	14,299.8	15,531.9	17,962.1	15,517.4	21,600.8	11,416.9	14,184.4	14,869.3
10	Dickinson Bayou	12,162.1	12,192.9	8,539.8	10,271.7	10,974.6	10,565.7	14,410.0	12,762.2	17,159.7	9,030.9	10,184.2	11,709.1
11	Live Oak Bayou[1]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
						Medium Flow							
1	Chocolate Bayou	39,951.2	34,749.9	21,350.9	17,604.9	37,004.4	33,286.6	57,692.1	26,515.5	50,928.2	35,163.8	27,659.6	20,909.3
2	Highland Bayou	5,406.4	4,062.2	3,436.1	3,190.3	4,383.0	3,845.7	7,070.4	4,657.0	6,096.5	4,265.2	3,515.8	3,465.7
3	Oyster Bayou	40,187.6	28,334.6	18,518.8	15,584.1	32,005.6	35,999.5	23,995.6	17,770.0	37,152.3	30,546.0	27,207.1	34,927.9
4	Robinson Bayou	11,011.1	7,578.8	5,199.4	5,402.6	9,717.9	10,949.2	7,090.8	4,970.9	10,498.9	7,742.7	7,603.8	8,927.6
5	Trinity River	383,940.4	532,064.2	518,700.4	501,094.1	866,032.0	589,627.2	180,501.9	92,081.9	78,554.4	211,243.2	278,098.5	477,034.8
6	Cedar Bayou	23,876.9	21,273.1	15,293.2	14,127.2	23,995.8	30,673.5	20,317.9	15,632.5	22,425.8	20,386.5	21,821.2	20,380.5
7	San Jacinto River	168,186.3	194,620.1	133,184.9	142,385.8	231,976.2	131,843.3	63,626.0	48,784.8	71,841.1	79,625.7	101,472.6	157,380.7
8	Buffalo Bayou	166,537.0	137,524.8	107,801.6	102,727.7	175,554.7	138,677.4	111,897.8	119,864.7	127,580.6	140,828.0	116,831.7	131,810.2
9	Clear Creek	33,175.0	30,008.8	22,575.3	18,438.2	35,029.0	37,199.5	41,014.9	25,968.9	38,186.0	30,205.6	28,015.4	22,462.1
10	Dickinson Bayou	25,426.9	20,924.0	16,600.4	15,449.9	25,818.0	22,644.1	32,637.3	21,405.7	30,167.1	23,265.2	19,153.0	17,535.1

(Continued)

[1] Hydrology provided listed this flow as 0.0, and was modeled as such. However, the flows should have been identical to those of 1990. It is thought that since this is such a small flow and identical flows were applied to base and all plans that the test results are sound.

Table B3 (Concluded)

Column	Name	Volume, acre-ft											
		January	February	March	April	May	June	July	August	September	October	November	December
Medium Flow (Continued)													
11	Live Oak Bayou	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
High Flow													
1	Chocolate Bayou	65,876.3	40,635.8	38,867.9	39,909.6	63,251.3	71,664.9	117,835.6	35,821.0	104,862.0	51,626.7	50,099.7	19,889.8
2	Highland Bayou	7,930.0	4,515.1	4,932.5	4,957.7	6,113.1	5,972.6	12,343.8	5,659.1	10,739.7	5,471.1	5,111.2	3,371.4
3	Oyster Bayou	68,155.4	33,483.0	36,001.8	39,530.2	56,891.3	82,099.4	50,529.4	24,865.4	78,902.2	46,112.8	51,598.4	32,967.1
4	Robinson Bayou	18,669.0	8,954.5	10,101.5	13,707.0	17,270.5	24,964.8	14,925.1	6,952.5	22,289.2	11,683.1	14,414.9	8,427.0
5	Trinity River	688,324.0	637,488.1	1,063,262.8	1,370,532.3	591,815.2	1,429,830.6	456,983.8	54,553.3	232,100.5	347,778.7	574,193.6	447,226.2
6	Cedar Bayou	38,129.6	24,596.9	26,412.4	29,890.9	39,469.0	64,673.4	37,918.8	20,240.6	43,406.2	28,933.3	38,436.9	19,427.2
7	San Jacinto River	279,020.6	228,604.5	250,491.2	346,453.6	404,288.2	286,574.2	120,805.5	63,840.4	141,135.2	115,244.6	184,592.2	149,045.0
8	Buffalo Bayou	267,800.4	159,155.9	189,060.0	223,896.2	292,386.5	283,217.0	205,323.1	157,661.7	244,705.8	201,192.7	203,206.5	125,594.4
9	Clear Creek	52,144.8	34,517.5	38,106.7	36,377.4	56,718.8	75,594.0	77,971.8	33,500.8	73,775.1	42,392.1	47,981.5	21,534.7
10	Dickinson Bayou	39,753.6	23,951.9	27,535.6	30,701.9	41,349.3	44,046.8	61,858.2	27,634.6	58,078.8	32,497.8	32,100.2	16,823.5
11	Live Oak Bayou	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table B4
2049 Hydrology

Column	Name	Volume, acre-ft January	February	March	April	May	June	July	August	September	October	November	December
	Low Flow												
1	Chocolate Bayou	16,901.2	18,618.5	9,428.9	11,123.3	13,074.2	12,794.9	21,418.1	14,757.0	26,847.9	10,798.4	13,043.1	13,516.1
2	Highland Bayou	4,431.8	3,957.0	3,748.8	4,149.4	4,378.4	4,312.3	5,555.3	4,915.3	5,438.2	3,857.7	3,736.9	4,055.4
3	Oyster Bayou	14,408.4	13,591.4	5,751.9	7,586.6	8,362.0	10,125.1	7,595.2	8,064.3	17,823.5	6,669.2	10,423.4	18,990.5
4	Robinson Bayou	3,965.0	3,650.9	1,631.8	2,633.9	2,553.3	3,093.8	2,261.8	2,274.7	5,053.3	1,714.6	2,928.7	4,873.0
5	Trinity River	102,508.0	228,423.8	117,693.9	206,355.9	172,865.5	115,945.1	8,549.7	5,868.1	7,432.0	1,156.8	73,367.9	233,373.8
6	Cedar Bayou	16,605.8	16,912.5	13,255.9	15,557.8	16,380.4	18,736.5	17,057.2	16,410.6	19,197.3	13,524.5	16,080.3	18,501.2
7	San Jacinto River	98,256.8	125,446.2	80,695.6	110,523.7	106,867.8	84,525.0	70,542.3	67,465.5	75,680.2	59,551.1	75,723.8	121,823.5
8	Buffalo Bayou	87,761.8	88,361.1	63,478.0	78,741.0	82,034.4	75,442.4	73,138.9	85,553.4	89,558.4	63,731.4	71,586.6	95,902.7
9	Clear Creek	20,719.0	21,511.1	16,436.1	18,194.7	20,483.0	21,782.4	24,615.8	21,700.6	27,246.3	16,860.8	19,157.9	19,977.2
10	Dickinson Bayou	12,741.0	12,703.2	9,141.5	10,934.3	11,675.3	11,274.1	15,164.1	13,462.9	17,799.5	9,647.9	10,747.9	12,288.0
11	Live Oak Bayou[1]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Medium Flow												
1	Chocolate Bayou	40,904.7	35,590.5	22,342.0	18,696.4	38,158.6	34,453.3	58,934.1	27,669.7	51,982.0	36,180.0	28,588.0	21,862.8
2	Highland Bayou	6,768.4	5,263.0	4,851.9	4,749.5	6,031.9	5,512.5	8,844.7	6,305.9	7,602.0	5,716.9	4,842.1	4,827.7
3	Oyster Bayou	40,303.4	28,436.6	18,639.2	15,716.7	32,145.7	36,141.2	24,146.4	17,910.1	37,280.3	30,669.3	27,319.8	35,043.7
4	Robinson Bayou	11,055.3	7,617.9	5245.4	5,453.3	9,771.5	11,003.4	7,148.5	5,024.5	10,547.8	7,789.8	7,646.9	8,971.8
5	Trinity River	384,332.0	532,409.5	519,107.4	501,542.3	866,506.1	590,106.4	181,012.0	92,556.0	78,987.3	211,660.6	278,479.8	477,426.4
6	Cedar Bayou	29,802.0	26,496.6	21,452.2	20,909.9	31,168.3	37,924.0	28,036.2	22,805.0	28,974.6	26,701.5	27,590.4	26,305.6
7	San Jacinto River	200,876.6	223,439.2	167,165.6	79,807.6	271,548.6	171,845.9	106,209.4	88,357.2	107,972.5	114,466.7	133,302.6	190,071.0
8	Buffalo Bayou	181,520.0	150,733.6	123,376.1	119,879.4	193,692.1	157,012.0	131,415.2	138,002.1	144,140.8	156,797.6	131,420.4	146,793.2
9	Clear Creek	38,282.9	34,511.8	27,884.8	24,285.3	41,212.2	43,450.0	47,668.6	32,152.1	43,831.5	35,649.5	32,988.9	27,570.0
10	Dickinson Bayou	26,005.8	21,434.3	17,202.1	16,112.5	26,518.7	23,352.5	33,391.4	22,106.4	30,806.9	23,882.2	19,716.7	18,114.0

(Continued)

[1] Hydrology provided listed this flow as 0.0, and was modeled as such. However, the flows should have been identical to those of 1990. It is though that since this is such a small flow and identical flows were applied to base and all plans that the test results are sound.

Table B4 (Concluded)

Column	Name	Volume, acre-ft											
		January	February	March	April	May	June	July	August	September	October	November	December
Medium Flow (Continued)													
11	Live Oak Bayou	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
High Flow													
1	Chocolate Bayou	66,829.8	41,476.4	39,859.0	41,001.1	64,405.5	72,831.6	19,077.6	36,975.2	105,915.8	52,642.9	51,028.1	20,843.3
2	Highland Bayou	9,292.0	5,715.9	6,348.3	6,516.9	7,762.0	7,639.4	14,118.1	7,308.0	12,245.2	6,922.8	6,437.5	4,733.4
3	Oyster Bayou	68,271.2	33,585.0	36,122.2	39,662.8	57,031.4	82,241.1	50,680.2	25,005.5	79,030.2	46,236.1	51,711.1	33,082.9
4	Robinson Bayou	18,713.2	8,993.6	10,147.5	13,757.7	17,324.1	25,019.0	14,982.8	7,006.1	22,338.1	11,730.2	14,458.0	8,471.2
5	Trinity River	688,715.6	637,833.4	1,063,669.8	370,980.5	1,592,289.3	1,430,309.8	457,493.9	155,027.4	233,533.4	348,196.1	574,574.9	447,617.8
6	Cedar Bayou	44,054.7	29,820.4	32,571.4	36,673.6	46,641.5	71,923.9	45,637.1	27,413.1	49,955.0	35,248.3	44,206.1	25,352.3
7	San Jacinto River	311,710.9	257,423.6	284,471.9	383,375.4	443,860.6	326,576.8	63,388.9	103,412.8	177,266.6	150,085.6	216,422.2	181,735.3
8	Buffalo Bayou	222,783.4	172,364.7	204,634.5	241,047.9	310,523.9	301,551.6	224,840.5	175,799.1	261,266.0	217,161.5	217,795.2	140,577.4
9	Clear Creek	57,252.7	39,020.5	43,416.2	42,224.5	62,902.0	81,844.5	84,625.5	39,684.0	79,420.6	47,836.0	52,955.0	26,642.6
10	Dickinson Bayou	40,332.5	24,462.2	28,137.3	31,364.5	42,050.0	44,755.2	62,612.3	28,335.3	58,718.6	33,114.8	32,663.9	17,402.4
11	Live Oak Bayou	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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13. ABSTRACT *(Maximum 200 words)*

This report describes the testing program conducted to evaluate the impact of enlargement of the Houston-Galveston Navigation Channel on the salinity and hydrodynamic fields of tidally influenced Galveston Bay. The present channel nominal dimensions are 40 ft deep at mean low water (mlw) and 400 ft wide. The proposed enlargements tested are for a channel 45 ft deep at mlw and 530 ft wide (Phase I) and 50 ft deep and 600 ft wide (Phase II). Current plans do not include the Phase II enlargement. Salinity fields for these channel configurations and the existing channel dimensions are compared. In a separate study the results from these simulations were used to drive an ecosystem model to predict oyster production.

Testing conditions included tidal conditions and winds for the year 1984. The freshwater inflows (developed outside this study) were tested for low-, medium-, and high-flow years. Additionally, since water demand in the future is expected to modify freshwater distribution and quantities, future distributions for the test year 1999 (Wallisville Dam in place), 2024, and

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The code used (RMA10-WES) is a Galerkin-based finite element solution to simulate three-dimensional (3-D) unsteady open-channel flow. The code represents 3-D hydrodynamics using conservation of fluid mass, horizontal momentum, and salinity/temperature transport equations subject to the hydrostatic assumption.

Results of these tests showed that the largest increases in salinity were in low-salinity areas, including the upper west side of the bay across the channel from Atkinson Island, and the upper bay channel. Trinity Bay showed a small salinity increase. South of midbay the salinity increases were generally less than 1 ppt. Some locations in the south bay near the navigation channel occasionally showed a decrease in salinity for the deeper channel configurations. These decreases occurred during the period of rebound in salinity after the high inflow period of late spring.

The deepened channels showed increased salinity stratification. The stratification increased with channel project depths and with freshwater inflow in the Buffalo Bayou/San Jacinto River Basin.

The future hydrologic scenarios result in more freshwater inflow to Galveston Bay through Buffalo Bayou and San Jacinto River. The deepened channels typically resulted in less significant salinity increases in the scenarios than for the present hydrologic year (1990). These future scenarios redistribute some of the freshwater inflow from the Trinity River and reintroduce it through Buffalo Bayou and San Jacinto River. The model indicates a corresponding increase in salinity in Trinity Bay and decrease in the western upper bay salinity.